Walter W. Bradley.

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
Ferry Building, San Francisco
OLAF P. JENKINS, Chief

Vol. 44 JANUARY 1948 No. 1

CALIFORNIA JOURNAL OF MINES AND GEOLOGY

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TRINITY
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
MENDOCINO
COLUSA
YUBA
NEVADA
PLACER
LAKE
SUTTER
EL DORADO
SONOMA
YOLO
ALPINE
NAPA
SOLANO
SACRAMENTO
AMADOR
CALAVERAS
MARIN
SAN JOAQUIN
TUOLUMNE
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MONO
SAN FRANCISCO
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SAN MATEO
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IMPERIAL
NEVADA
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OCEAN
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ANDALUSITE & KYANITE
BARITE
BORAX
BUILDING STONE
CARBON DIOXIDE GAS
CHROMITE
CLAY
COAL
COPPER
DIATOMITE
DOLOMITE
FELDSPAR
FELDSPAR & SILICA (QUARTZ)
GOLD DISTRICTS
GOLD (SMALL AREAS OR MINES)
GYPSUM
IRON
LEAD
LIMESTONE, CEMENT & MARBLE
MAGNESITE
MANGANESE
POTASH
PUMICE & VOLCANIC ASH
PYRITES
QUICKSILVER
SALT
SILICA (QUARTZ)
SILICA (SAND)
SILVER
SODA
SULFUR
TALC & SOAPSTONE
TITANIUM
TUNGSTEN
ZINC
GAS DISTRICTS
OIL & GAS DISTRICTS
CITIES
NOTE
COMBINED SYMBOLS SHOW TWO OR MORE MINERALS OCCUR AT SAME LOCALITY
BORAX, SODA
COPPER, ZINC

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TRENDS IN THE FOUNDRY-SAND INDUSTRY

By Leonard O. Hofstetter *

The foundry industry is a basic one. Almost every accessory to human activity depends upon castings, from typewriters and sewing machines to locomotives and airplanes. Foundries turn large quantities of raw materials into castings for all lines of industry. One of the most important raw materials is sand, which is used for making molds and cores. As the foundry industry develops, better sands are constantly required.

Many old-time foundrymen will recall that, as little as 15 years ago, only four or five grades of naturally bonded foundry sands were being produced in the State of California; and that these in general reached the foundry because someone was making an excavation and decided that the material being moved might make a good foundry sand. Little attempt was made to maintain uniformity and practically none of the sand reaching the market at that time was mulled, screened, or classified in any way. As a result, many of the foundrymen who were required to maintain a uniform quality of castings found it advisable to use sands which were shipped into California from other parts of the United States and foreign countries.

Considerable naturally bonded molding sand reach the state from Albany, New York, and some small amounts were imported from France. The unbonded silica sands were imported mainly from Belgium, and considerable quantities came by water from New Jersey. The all-rail movement of silica sands for steel foundries from the Ottawa-Illinois district had accelerated with the growth of the steel-casting industry. At the present time, in addition to the Ottawa sand, there is considerable silica sand moving into California from the states of Nevada, Utah, and Arizona. Occasional shipments of naturally bonded sand come in from Albany, New York, and from Tennessee.

The present trend in foundry-sand practice is toward the increased use of so-called ''synthetic sands.'' In using a sand of this kind, a foundryman does not depend upon sand grains which have received a coating of clay by nature, but starts with an unbonded, or lightly bonded, sand and adds clays and other binders to develop the properties which are necessary to produce the type of casting he is making. The three main requirements of the base sands are adequate refractoriness, proper grain size, and sufficient durability.

A sand is said to be adequately refractory for the production of any particular casting when the grains do not fuse or vitrify excessively when molten metal is poured into the mold cavity. Naturally, refractory requirements vary over a wide range, as various metals are cast at temperatures ranging from 750 degrees to 3,000 degrees Fahrenheit.

Grain size and distribution of the sand is important in order that the mold may have sufficient permeability and yet minimize casting defects such as buckling. This may be caused by high expansion or metal penetration, resulting from high permeability of the sand.

* Vice President, Southern California Chapter, American Foundrymen's Association. Manuscript submitted for publication October 1, 1947.

Durability of the sand grain is important because in foundry operations the sand is subjected to great thermal shock, as well as mechanical abrasion. If the sand grains break down too rapidly, they tend to produce an excessive amount of fine material, which naturally results in low permeability.

As a result of this trend toward the use of synthetic sands and the improved properties it is possible to obtain with their use, there is a growing insistence on the part of foundrymen that the sands reach them clean, dry, and ready to use. Most foundrymen today prefer purchasing a dry sand ; although most sands are mixed with water before being used. However, when starting with a dry sand, it is possible to add a definite amount of water to each batch and thus obtain the uniform moisture content which is so important in maintaining uniform properties of molding and core sands.

The producers of naturally bonded sand will find it increasingly necessary to maintain uniform quality as to grain size and distribution, clay content and moisture, if they are to maintain their position in the foundry-sand market. It is to be hoped that the beginning which has been made in the present report will lead to continued work by the State of California, Division of Mines, as well as the sand producers of the state, foundries, and the American Foundrymen's Association. There seems little doubt that there are a number of other minerals beside silica which would produce superior foundry sands, but to date their cost has been so high as to make their use prohibitive, except for special and experimental work. Possibly the real "Old-Timer" of the next generation of foundrymen will be one who can remember "way back when they used silica sands."

PROPERTIES OF FOUNDRY SANDS

By Heinrich Ries *

OUTLINE OF REPORT

ILLUSTRATIONS

INTRODUCTION

The term *foundry sand* includes: (1) *molding sand*, used for making molds in which molten metal is poured; and (2) *core sand*, used for making cores, which occupy space within the mold and produce a hollow in the casting.

Molding sands may be further subdivided into: (1) *naturally bonded sands*, in which the sand grains and clay bond occur already mixed by

* Chairman, Sand Division, American Foundrymen's Association. Manuscript submitted for publication October 1, 1947.

nature; and (2) so-called *synthetic sands*, which consist of an artificial mixture of clean sand and clay bond. Synthetic sands are now universally used in making molds for casting steel and sometimes for other metals.

The term *blended molding sand* is sometimes used to refer to mixtures of naturally bonded sands or to mixtures of naturally bonded and synthetic sands. *Sharp sand* is a term often applied by foundrymen to a clay-free sand, and has no reference to the shape of the grains.

All molding sands have a certain amount of moisture added to them in order to make the particles adhere. Binders may also be added in order to produce the desired physical properties. Core sands have oil and moisture added as well as various binders.

A distinction is sometimes made between *facing* and *backing* sands. The former make up the face of the mold and are designed to give a smooth surface to the casting. Behind the facing sand is the backing sand. Separate facing mixtures are not always employed.

It is the aim of foundrymen to use a sand mixture with properties that will produce castings free from flaws. Mixtures satisfactory for brass may not be suitable for iron or steel; and even the mixtures used for any one kind of metal vary with casting size and shape, with metal-section thickness, and with pouring temperature.

It has been suggested that one fixed mixture could be prescribed for brass, another for iron, and so on. This, however, is impracticable, for the same sand cannot be used or obtained all over the country, whereas it is possible to use different sands and different mixtures for the same product.

If a certain mixture works well, it is desirable to keep it as uniform as possible and for this reason the properties of the mixture such as moisture content, strength, and permeability may be tested daily or oftener in the foundry laboratory. This testing is known as *sand control,* and is practiced by many foundries.

It is also desirable that the sand producer ship a product that maintains uniformity. More attention is given to this by some sand producers than by others, so that some foundries purchase their sands on specification. In such cases, care should be taken not to make the specifications too strict.[1]

DEFINITION OF SAND

The term *sand* in this paper is applied to those grains of mineral matter which range in size from 2 millimeters to 0.05 of a millimeter (1/12 to 1/500 of an inch). *Natural sand* is naturally occurring material composed of grains that form loose aggregates, or material of granular character that separates easily along the natural boundaries of the grains. *Aritificial sand* is that obtained by crushing a hard rock, such as well-indurated sandstone or granite, to grains of sand size.

ORIGIN OF SAND

Sand deposits may be of two general types, residual and transported.

Residual sands are formed by the disintegration of the bed rock in place by mechanical processes of weathering. This results in the material breaking down to an incoherent mass of grains. Where chemical proc-

[1] An interesting paper on preparation of foundry sand for the market by F. P. Goettman was presented at the 1947 convention of the American Foundrymen's Association. It was issued as preprint No. 47-12.

esses are involved some of the rock minerals may decompose and yield a clay instead of a sand. For example, granite in dry climates breaks down by weathering to sand, while in moist climates it yields a clay. Residual sands are common only in arid climates, and few are used in foundry work.

Transported sands have been deposited by wind or water. Wind-blown sands are heaped into dunes which may occur along a coast, or inland in arid areas. Such deposits are usually free from clay and may show a stratified structure. Dune sands are common along the California coast and are excavated at several localities for foundry use. The mineral composition of dune sands is variable.

Sands transported by water may have been deposited under a variety of conditions—along the flood plains of streams, in lakes, as beach deposits, or in the ocean adjoining the coast. The last-named may be found above sea level at the present time, where elevation of the land has occurred since their deposition. Transported sands vary greatly in their coarseness and may contain a variable amount of clay; in some instances beds of clay may be interstratified with beds of sand. Deposits of stratified sand may become consolidated to form sandstone. Sandstone is sometimes crushed for foundry use, as in the processing of Eocene sands of the Pittsburg-Antioch area of California.

MINERAL COMPOSITION

Most natural sands are composed entirely or largely of grains of quartz or silica, but there may be feldspar grains mixed with the quartz. Most California sands and sandstones are feldspathic.

In some regions sands consist predominantly of other minerals. Thus along the southern California coast some sands contain an appreciable quantity of ilmenite ($FeO.TiO_2$); on the southern Florida and some Hawaiian coasts, the grains are mainly calcite ($CaCO_3$). Other sands consist largely or wholly of grains of volcanic rock, gypsum ($CaSO_4.2H_2O$), magnetite (Fe_3O_4), zircon ($ZrSiO_4$), or olivine [$(MgFe)_2SiO_4$]. The term "sand," therefore, refers to the size of the grains and not their mineral composition.

Most of the sand used in foundry work is siliceous. Zircon sands are used in special cases because of their high refractoriness, and the use of ilmenite and olivine sands has been suggested for the same purpose.

GRAIN SHAPE

Sand grains may vary in shape from well rounded to angular. They are usually classified as round, subangular, and angular. The degree of roundness (or angularity) of a grain can be expressed mathematically.[2] In addition, there may be compound grains, which consist of a number of individual grains cemented together. They occur usually only in sizes above 12 mesh.

Well-rounded grains are comparatively rare even in those sands in which they are most common, such as the Ottawa, Illinois, silica sand. Even here well-rounded grains are not common below 40 mesh, the smaller sizes usually being angular or subangular.

[2] Davies, W., and Rees, W. J., The effect of grain shape on the moulding properties of synthetic moulding sands: Iron and Steel Inst., Steel Castings Research Comm. Paper, No. 8, 1944.

GRAIN SURFACE

In addition to a variation in shape, grains may also show considerable difference in surface character. Some are quite smooth while others are rough. Roughness probably gives better adherence between grain and bond. If the surface of the grain is covered with a thin coating of adhering clay or iron oxide, the adherence between grain and clay is probably still further increased.

GRAIN FRACTURES

Many sand grains when carefully examined under the microscope are seen to be traversed by irregular fractures, often incorrectly referred to as cleavage; others are free from such fractures. Some sand grains show a tendency to crack under the influence of heat; others do not. This cracking may result from the fractures. A considerable quantity of fines is thus produced.

GRAIN SIZE OF SANDS

Sands may be made up of particles ranging from coarse to very fine.[3] In order of decreasing size, the particles are termed sand, silt, and clay. Sand as usually recognized ranges from 2.0 to 0.05 millimeters (.079 to .00197 inches) in diameter; silt ranges from 0.05 to 0.002 millimeters (.00197 to .000079 inches); clay is composed of any particles smaller than silt.[4] While different organizations interested in sand use the terms "sand," silt," and "clay," the actual limits are not the same in all systems of classification.

In the American Foundrymen's Association fineness test, the material finer than about 20 microns (0.02 mm) is classified as A.F.A. clay and includes both fine silt and true clay.

In many sands the grains may be concentrated largely on three adjacent sieves, while in others they may be distributed over a wide range of sieves from 6 mesh to 350 mesh. The fineness of a sand may be expressed in two ways[5] (fig. 1): (1) the *size-frequency curve,* in which the percentage retained on each sieve is recorded; and (2) the *cumulative curve,* points on which represent percentage of particles larger than the sieve size designating that point.[6]

The cumulative curve has several advantages. It gives a smooth curve instead of a broken line as in the size-frequency curve. Sieves that retain very little material can be eliminated, or others can be added without distorting the curve. Faulty sieves may be indicated by a break occurring at the same place in the curve, when different samples are sieved. Cumulative curves can be used for specification testing by having the specification limits plotted as two curves. If the sand to be tested meets the specifications, its points will fall between the two limiting curves already plotted. Finally, size data for silt and clay particles obtained with the hydrometer can be plotted on the same graph as a continuation of the line presenting the sieve data.

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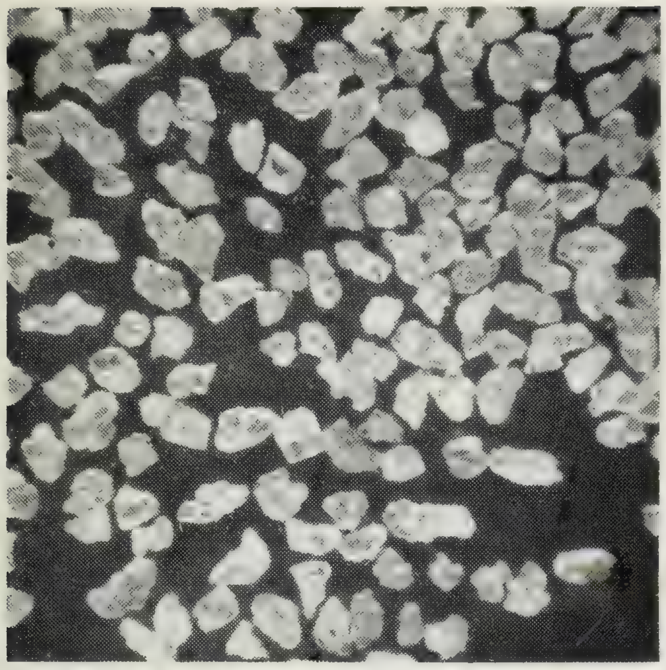
[3] Ries, H., and Conant, G. D., The character of sand grains: Am. Foundrymen's Assoc. Trans., vol. 39, p. 353, 1931.

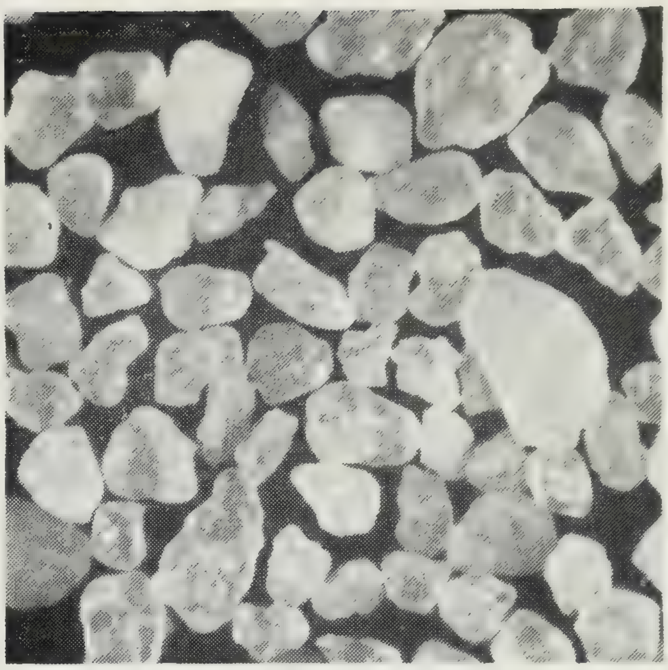
[4] The size of finer particles is sometimes expressed in microns. One micron is 1/1000 mm.

[5] Morey, R. E., New tentative standards for grading and fineness of sands: Am. Foundrymen's Assoc., Preprint 47-29, Annual Meeting 1947. . . Am. Inst. Min. Met. Eng. Trans., vol. 57, p. 462, 1933.

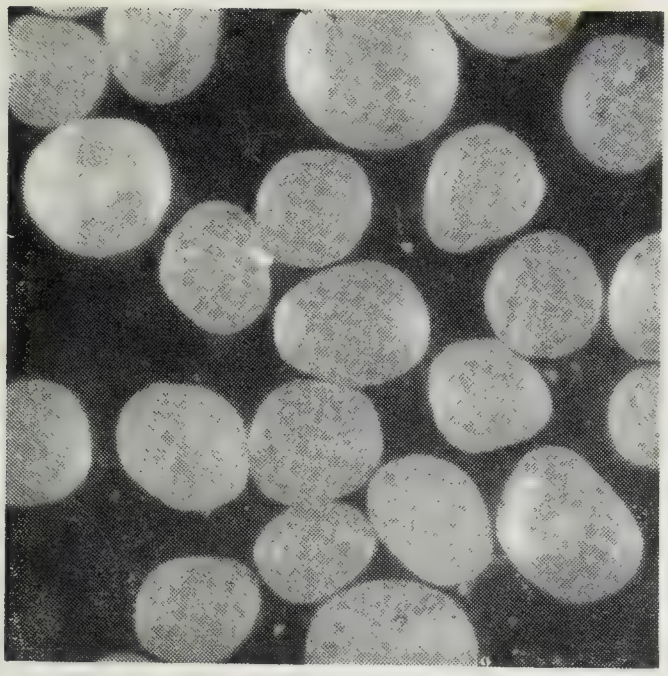
[6] Morey, R. E., and Taylor, H. F., Use of the cumulative curve for foundry sand control: Am. Foundryman, vol. 9, p. 65, 1946.



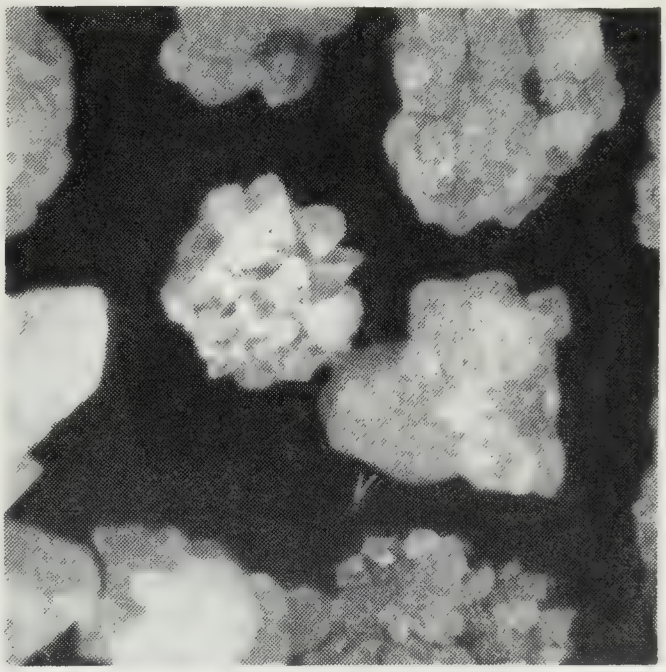
A, ANGULAR GRAINS



B, SUBANGULAR GRAINS



C, ROUND GRAINS



D, COMPOUND GRAINS

PHOTOMICROGRAPHS OF FOUR SANDS SHOWING GRAIN-SHAPE TYPES

Photos by H. Ries

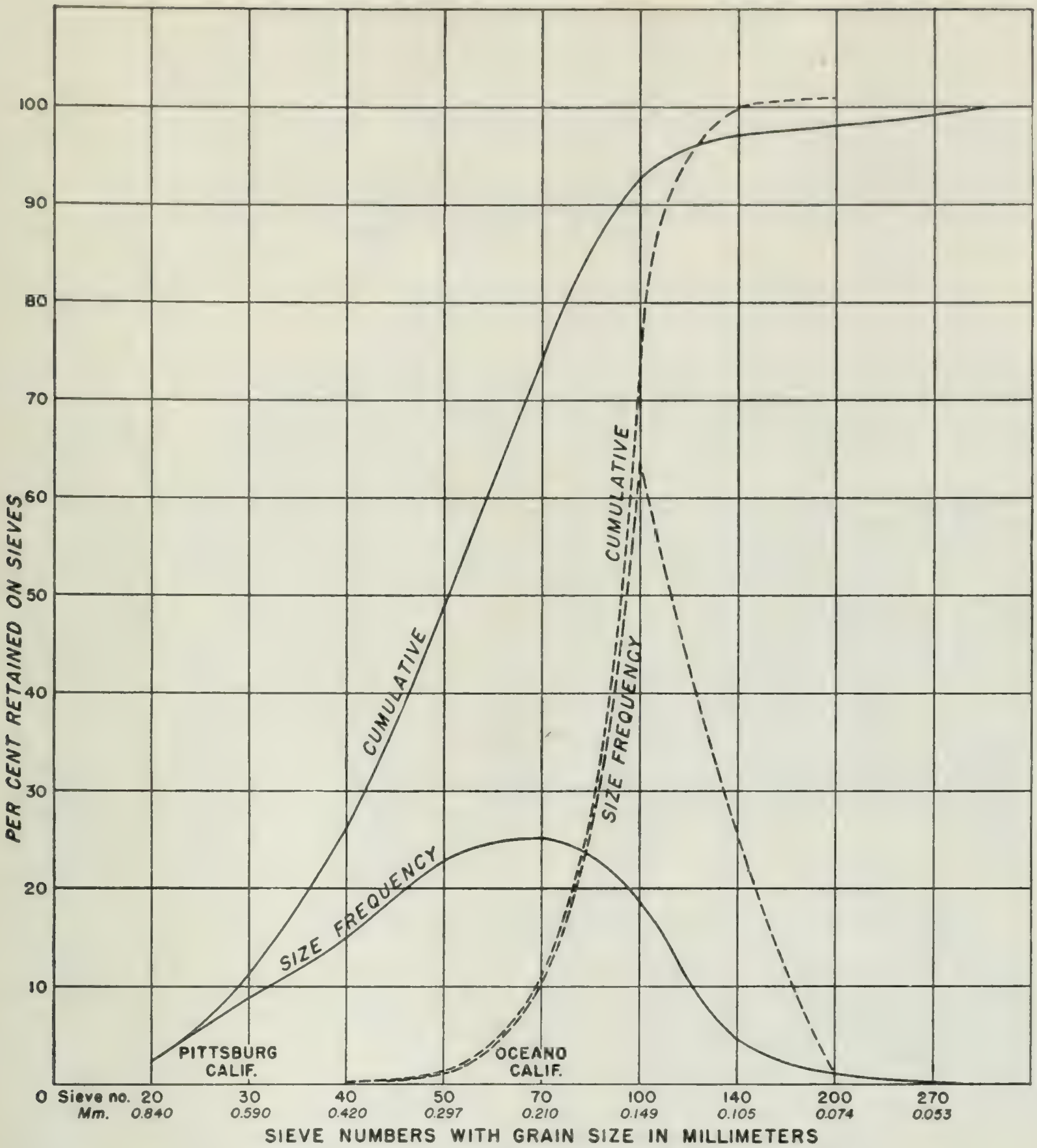


FIG. 1. Curves constructed from sieve analyses of two foundry sands, to show comparison of size-frequency and cumulative curves. Sands from Pittsburg, Contra Costa County, and Oceano, San Luis Obispo County.

DETERMINATION OF FINENESS

Briefly, the determination of the fineness of a clean, clay-free sand is obtained by placing a 50-gram sample on the top unit of a nest of sieves arranged in decreasing mesh size from top to bottom. The set is then placed in a shaking apparatus and run for 15 minutes, after which the sand on each sieve is weighed.[7]

Two sets of sieves are in use, the U.S. series, and the Tyler series. The openings of similarly numbered sieves of both sets are the same, but the series numbers are in some cases slightly different.

If the sand contains clay, this must be separated first by agitating the mixture with water and sodium hydroxide in a proper stirring jar, and allowing the dispersed material to stand. Material which does not

[7] Handbook of testing sands and clays, 5th ed., Am. Foundrymen's Assoc., 1945.

Sieve numbers in the U. S. and Tyler series

U. S. series	Tyler series	U. S. series	Tyler series
6	6	70	65
12	10	100	100
20	20	140	150
30	28	200	200
40	35	270	270
50	48	---	---

Table 1. Sieve tests of sands free from clay

Sieve size	A		B		C	
	Percent retained	Cumulative	Percent retained	Cumulative	Percent retained	Cumulative
On 12						
20					2.26	2.26
30	.04	.04	.04	.04	8.84	11.10
40	.08	.12	.16	.20	15.00	26.10
50	.96	1.08	1.44	1.64	22.84	48.94
70	9.56	10.64	6.84	8.48	26.18	75.12
100	63.76	74.40	27.20	35.68	18.64	93.76
140	25.62	100.02	36.92	72.60	4.52	98.28
200	.92	100.94	22.00	94.60	1.00	99.28
270			2.92	97.52	.24	99.52
Pan			.88	98.40	.48	100.00
Total	100.94		98.40		100.00	
A.F.A. fineness	76		97		49	

A—Oceano, California.
B—Nevada pink, Overton, Nevada.
C—Pittsburg, California.

Table 2. Calculation of A. F. A. grain-fineness number

Sieve size	Amount of 50-gm. sample retained on sieve		Multiplier	Product
	Grams	Percentage		
6	None	0.0	3	0
12	None	0.0	5	0
20	None	0.0	10	0
30	None	0.0	20	0
40	0.20	0.4	30	12
50	0.65	1.3	40	52
70	1.20	2.4	50	120
100	2.25	4.5	70	315
140	8.55	17.1	100	1,710
200	11.05	22.1	140	3,094
270	10.90	21.8	200	4,360
Pan	9.30	18.6	300	5,580
Total	44.10	88.2		15,243

$$\text{A. F. A. grain-fineness number} = \frac{\text{Total product}}{\text{Total percentage retained grain}} = \frac{15243}{88.2} = 173.$$

settle more than one inch in a minute is termed A.F.A. clay and includes material up to 20 microns (.02 millimeter) or fine silt and clay. Two sands might therefore have the same amount of A.F.A. clay, but differ in their green strength because they contain different amounts of silt. If this is the case, and more information is desired regarding the character of the A.F.A. clay, its fineness should be determined by means of a hydrometer.[8]

Table 1 gives the fineness tests of three sands, all of which are free from A.F.A. clay,[9] recorded by both the size-frequency and the cumulative methods.

CALCULATION OF FINENESS

Before the averaged fineness of a sand can be determined its A.F.A. clay content must first be separated from the sand grains. Instructions for this procedure are given in the A.F.A. Handbook.[10] The grains are then separated into size groups by sieving.

A 50-gram sample of the sand is usually taken for this test (see table 2). To calculate the A.F.A. grain-fineness number, multiply the weight of sand retained on each sieve (column 2) by two. This gives the true retained percentage of each sieve sample. Multiply the percentage (column 3) by the multiplier (column 4). Divide the sum of these products (column 5) by the total percentage of grains retained on the sieves (column 3) to obtain the A.F.A. grain-fineness number.

The grain-fineness number does not, however, give definite information regarding the distribution of the grains of different sizes, for two sands of the same grain fineness number might show quite different grain distribution (see table 3).

EFFECT OF SHAPE AND SIZE OF SAND GRAINS

Certain generalizations may be made regarding the effect of sand grains on properties of the sand. A sand composed predominantly of large grains will, other things being equal, show a higher permeability than one composed largely of small grains. Mixing smaller grains with large ones decreases the permeability because the small grains fill in the spaces between the larger ones. This is shown by a determination of the base permeability of such a mixture.

The base permeability does not increase rapidly with increase in grain size up to 140 mesh, so long as the grains in each sample are of uniform size. If large grains are added to small ones, the base permeability decreases at first, but increases with the addition of a larger percentage of the coarse grains. Base permeability also decreases with an increased spread of grain size.[11]

Sands with rounded grains are said to show greater flowability than sands with angular ones,[12] and coarse-grained sands greater flowability

[8] Morey, R. E., New tentative standards for grading and fineness of sands: Am. Foundrymen's Assoc., Preprint 47-29, Annual Meeting 1947. . . Am. Inst. Min. Met. Eng. Trans., vol. 57, p. 462, 1933.

Morey, R. E., and Taylor, H. F., Some properties of synthetically bonded steel sands: Am. Foundrymen's Assoc. Trans., vol. 49, p. 388, 1941.

Morey, R. E., and Taylor, H. F., Use of the cumulative curve for foundry sand control: Am. Foundryman, vol. 9, p. 65, 1946.

[9] Handbook of testing sands and clays, 5th ed., Am. Foundrymen's Assoc., 1945.

[10] Handbook of testing sands and clays, 5th ed., Am. Foundrymen's Assoc., 1945.

[11] Morey, R. E., and Taylor, H. F., Some properties of synthetically bonded steel sands: Am. Foundrymen's Assoc. Trans., vol. 49, p. 388, 1941.

[12] Briggs, C. W., The metallurgy of steel castings, 1st ed., New York, McGraw-Hill Book Co., Inc., 1946.

Table 3. Grain-size differences in two sands with similar grain-fineness numbers

U. S. sieve size	Percent retained, sand sample 1	Percent retained, sand sample 2
On 20	.02	2.26
30	.44	8.84
40	4.36	15.00
50	30.24	22.84
70	53.24	25.18
100	12.00	18.64
140	----------	4.52
200	----------	1.00
270	----------	.24
Pan	----------	.48
Grain-fineness number	48	49
Base permeability	210	125

than fine-grained sands. Round-grained sands show higher green compression strength than sands with angular grains [13] (see table 8). Angular grains can be rammed to a harder mass than rounded ones, and hence the danger of cutting or scabbing is decreased.[14] A coarse-grained sand is more subject to metal penetration than a fine-grained sand.

THE BOND OF FOUNDRY SANDS

In both naturally bonded and synthetic sands, clay forms the bonding material which makes the sand grains adhere when moist. In naturally bonded sands the clay may contain a variable admixture of fine silt; in synthetic sands the added clays are usually comparatively free from this material.

True clay consists of particles which are under 0.002 of a millimeter (0.000079 in.) in diameter. Particles 0.002 of a millimeter in diameter require about 2 hours to settle 1 inch, when dispersed in water.

According to A.F.A. standards, clay [15] includes all material which, when suspended in quiet water, will not settle at a rate of more than 1 inch per minute. It therefore consists of clay particles and fine silt.

Fine silt has little bonding power and when mixed with true clay usually decreases the bonding power of the latter.[16] Two sands having the same grain distribution and same A.F.A. clay content, therefore, might differ in their bonding strength, depending on the relative amounts of clay and fine silt present in the material.

The clay minerals in clay-bearing foundry sands and bond clays used in synthetic sands belong to three important groups: kaolinite, montmorillonite, and illite. A fourth group, halloysite, not so widely used, has only recently appeared on the market. The particles of these minerals are usually flake-like except those of halloysite, which are more lath-like. They are so small that they possess colloidal properties, the

[13] Davies, W., and Rees, W. J., The effect of grain shape on the molding sands: Iron and Steel Inst., Steel Castings Research Comm. Paper, no. 8, 1944. See also Ries, H., and Lee, H. V., Relations between shape of grain and strength of sand: Am. Foundrymen's Assoc. Trans., vol. 39, p. 857, 1931. An opposing point of view may be found in Dunbeck, N. J., Molds and core materials, Am. Foundrymen's Assoc., Southern California Chapt., February 11, 1946.

[14] Briggs, C. W., idem.

[15] Handbook of testing sands and clays, 5th ed., Am. Foundrymen's Assoc., 1945.

[16] Ries, H., and Hills, R. C., Effect of silt on sand bonding strength: Am. Foundrymen's Assoc. Trans., vol. 4, no. 3, p. 158, 1933.

particles being smaller than 0.000079 of an inch, or 2 microns. All of these clays may carry some admixed grains of silica. The plasticity and, consequently, the bonding power of these several groups varies and is related to the base exchange capacity of the clay.[17]

Kaolinite

The mineral kaolinite has the formula $(OH)_8Al_4Si_4O_{10}$. Most kaolinite clays have low bonding properties as compared with montmorillonite. In fire clays kaolinite is the common clay mineral, but according to Grim and Cuthbert,[18] the fire clays of Illinois and Ohio have small amounts of illite associated with it. This is not necessarily true of all fire clays. The fire clays are refractory and have a low base-exchange capacity.

Montmorillonite

The clays of the montmorillonite group have the general formula $(OH)_4Al_4Si_8O_{20}nH_2O$. In some of them, alumina is replaced by magnesia or iron. They have a high base-exchange capacity. Their properties may vary depending on whether they have adsorbed hydrogen, sodium, or calcium.

Grim and Cuthbert [19] recognize two montmorillonite types. In one type, alumina is replaced by some magnesia, but not appreciably by iron. Sodium is the chief exchangeable base. These clays swell rapidly in water. The deposits in the Black Hills of Wyoming and South Dakota represent this first type. Montmorillonite of the second type has much alumina replaced by iron, and carries calcium and also hydrogen as the chief exchangeable bases. It swells slightly and disperses easily in water but does not form permanent suspensions. Montmorillonite found in Mississippi is of this type.

The clays in which montmorillonite predominates are generally referred to as bentonites. Their bonding power is stronger than that of fire clays and smaller amounts are thus required. They are not refractory. The southern bentonites show greater green strength and lower hot strength than the western ones.

Grim and Cuthbert [20] suggest that there may be bentonites that do not fit into these groups.

Halloysite

Grim and Cuthbert recognize two members in the halloysite group.[21] One has the formula $(OH)_8Al_4Si_4O_{10}$ and the other $(OH)_{16}Al_4Si_4O_6$. The latter changes to the former by loss of water at 140° F.[22]

Halloysite is highly refractory and has moderate shrinkage and plasticity. It disperses rapidly in water but has low base-exchange properties. Grim claims that the bonding properties of halloysite depend on the form of halloysite present, but believes that the best bonding properties are developed when both forms of halloysite are present. Most of the halloysite sold to foundries has come from the Eureka district of Utah. It is also known to occur in Indiana, Missouri, and Georgia.

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[17] Grim, R. W., and Cuthbert, L., The bonding action of clays: Illinois Geol. Survey Rept. Inv. 102, pt. 1, 1945.
[18] Idem.
[19] Op. cit.
[20] Op. cit.
[21] Op. cit.
[22] Grubb, A. A., Comparison of green bond test methods: Am. Foundrymen's Assoc. Trans., vol. 36, p. 709, 1928.

Table 4. Effect of different clays on properties of mixture

	Percent moisture	Green comp. strength psi	Dry comp. strength, psi.	Hot comp. strength, psi 2,000° F	Green perm.
4% southern bentonite	2½	9.9	47.0	25	178
5% western bentonite	2½	9.6	88.0	490	165
10% fire clay	3½	8.7	57.5	295	103

Table 5. Tests on several clays

	Western bentonite	Fire clay	Southern bentonite	3.4% western bentonite, 3.4% fire clay	2.5% western bentonite, 2.5% southern bentonite	3.0% fire clay, 3.0% southern bentonite
Percent bond	5	12	5	6.8	5	6.0
Percent moisture	2.5	3.0	2.5	2.8	2.5	3.0
Permeability	175	97	180	150	176	150
Green compression strength, psi	9.2	11.2	11.7	9.8	9.5	11.2
Dry compression strength, psi	79	64	45	130	65	60
Hot compression strength, psi						
500°F	65	50	20	52	35	45
1000	63	89	39	195	47	52
1500	320	92	29	530	140	67
2000	480	395	25	850	85	167
2500	8	6	5	9	6	5

Table 6. Variation of green permeability, green compression and dry compression with moisture content

Percent moisture	Green permeability	Green compression strength, psi	Dry compression strength, psi
1.60	140	6.9	7
2.30	193	6.8	15
3.30	197	4.6	25
4.33	152	3.7	33
5.30	125	1.3	40
3.72	16.0	9.5	----------
5.30	39.0	8.9	13.0
7.30	49.0	11.8	22.0
9.67	40.0	10.6	42.0
12.25	17.0	10.8	98.0
3.10	5.8	5.9	10.0
4.50	15.0	7.1	14.0
5.80	21.1	10.0	20.0
7.80	24.0	8.3	38.0
9.70	20.0	8.0	65.0
11.96	8.7	7.1	174.0

Illite

Illite is a mica-like clay mineral similar to muscovite. The name was proposed by Grim, Bray, and Bradley, who suggested the general formula $(OH)_4K\gamma(Al_4Fe_4Mg_4Mg_6)\ (Si_8{-}\gamma Al\gamma)O_{20}$ in which the value of γ varies from about 1 to 1.5. Illites do not all have good bonding properties; they are non-refractory (2500° ±) and disperse easily in water.

The bond clay from Illinois commercially known as *grundite* is chiefly illite, but contains a little kaolinite. An illite clay is also produced in Michigan under the commercial name *mincobond.*

Bond Clays in Synthetic Sands

In recent years bond clays commonly have been added to clay-free sands. There are some silica sands on the market that have a small amount of bond, perhaps 1 to 3 percent, and some bond clay may be added to these to bring the total bond to the proper amount. In some cases sand producers add the clay to a clean sand at the pits and sell the mixture to the foundry.

The figures in table 4 [23] show that less bentonite than fire clay is required to develop a given green strength. They also indicate that the southern bentonite has lower dry compression and hot strength than the western bentonite.

The figures in table 5, supplied by Sanders,[24] show the results of tests made on a mixture of bond clays and Michigan City sand with a fineness number of 53 to 55. They show the properties of bond clays alone, and also of mixtures of the different bond clays.

Dunbeck [25] has summarized the properties of synthetic sand as follows:

Advantages

1. There are savings through rebonding of sand otherwise discarded.
2. They have greater durability than naturally-bonded sands.
3. Synthetic sands are more uniform than naturally-bonded sands.
4. The base sand is free from silt. This results in higher permeability, better flowability, and needs less tempering water.
5. Synthetic sands are more refractory and have higher sintering points than naturally-bonded sands.
6. Synthetic sands are easy to control.

Disadvantages

1. Synthetic sands are workable over narrower moisture range than naturally-bonded sands.
2. Synthetic sands dry out more quickly.
3. There is greater difficulty in finishing and patching synthetic sand molds.

The strength of a clay depends on the ease with which it combines mechanically with water to form a plastic mass, and on the degree of plasticity. Different clays vary in this respect. Coarsely ground clays may work as well as finely ground ones if they slake easily when ground with water.

MOISTURE

All molding sands have moisture added to them when mixed or mulled. The amount added depends on the nature of the mix. For any

[23] Dunbeck, N. J., Molds and core materials: Am. Foundrymen's Assoc., Southern California Chapt., Feb. 11, 1946.
[24] Sanders, C. A., Foundry sand practice: Am. Colloid Co., Bull. 240, 1946.
[25] Dunbeck, N. J., American synthetic sand practice: Am. Foundrymen's Assoc. Trans., vol. 49, p. 141, 1941.

given mixture the properties, such as green strength and permeability, vary according to the amount of water added. With continued addition of water to the sand, green strength and permeability increase to a maximum value, and then decrease. At the point of maximum value the sand is said to have its *optimum* water content.[26] In the case of dry compression the strength increases as the moisture increases. This is shown in table 6, from data given by A. A. Grubb.[27]

The curves of green strength and green permeability, therefore, show a peak, and the steepness of the curve varies with different sands. For any given sand the peaks of permeability and green compressive strength do not always occur at the same moisture content. In synthetic sands, the peak of the curve is not at the same point for different amounts of clay bond but tends to occur at increasing moisture contents as the amount of bond clay is increased.[28]

The optimum water content does not necessarily mean the best working condition of the sand. This condition, referred to as *temper,* is usually a little on the wet side of the peak.

PERMEABILITY AND POROSITY

The term *permeability* as applied to foundry sands refers to the freedom with which the material permits gases to pass through it. *Porosity,* on the other hand, refers to the percentage of pore space between the grains. The two terms are sometimes confused. Two sands may have the same porosity, but the permeability of one may be high because of large pores, while that of the other is low because of smaller pore spaces.

Permeability is important, for, when hot metal comes into contact with a sand mixture that contains water and organic materials, there is generated a mixture of water vapor and the products of combustion. If the generated products cannot easily pass through the sand mixture they may be forced into the molten metal, causing defects such as blow holes and porosity. The volatile products that must escape through the mold are usually referred to by foundrymen as *mold gases.*

The following kinds of permeability are recognized: (1) green permeability, or the permeability of the green sand; (2) dry permeability, or the permeability of the dried sand; (3) base permeability, or the permeability of the clean sand, free from bond or moisture; (4) hot permeability, or the permeability of the sand mixture tested above room temperature, generally a temperature of redness or higher.

Factors Affecting Permeability

Some of the factors that affect permeability of sands are: (1) fineness and distribution of sand grains; (2) quantity and character of A.F.A. clay content; and (3) amount of moisture added.

Fineness and distribution of sand grains have a marked effect on permeability. This is best illustrated by a base-permeability test, in which no clay or moisture are present to affect the results. According to Reichert, a sand composed entirely of 20-mesh grains has a base permeability of 1796, while a similar mass of pan material of minus 270-mesh has only 6.9

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[26] Ries, H., and Rosen, J. A., Foundry sands: Michigan Geol. Survey Ann. Rept. 1907, p. 50.

[27] Grubb, A. A., Comparison of green bond test methods: Am. Foundrymen's Assoc. Trans., vol. 36, p. 709, 1928.

[28] Grim, R. W., and Cuthbert, L., The bonding action of clays: Illinois Geol. Survey Rept. Inv. 102, pt. 1, 1945.

Table 7. Effect of moisture and grain fineness on permeability

Moisture percent	Permeability of naturally bonded sands		Permeability of synthetic sand
	A	B	C
3.0	15.5	30.5	70
4.0	17.5	33.7	98
5.0	19.0	34.0	103
6.0	15.5	33.0	80
7.0	17.0	32.5	57
8.0	16.0	31.5	38

A—A. F. A. grain fineness 175; percent A. F. A. clay 9.3
B—A. F. A. grain fineness 135; percent A. F. A. clay 12.0
C—A. F. A. grain fineness 90; percent A. F. A. clay 16.0

permeability. Below 140 mesh an increase of grain size produces a slow increase in base permeability. Above this value the increase is more rapid. Base permeability drops rapidly with the addition of fine grains that fill the pore spaces between the larger grains. Reichert states that 10 percent pan material reduces the base permeability of a 70-mesh sand from 200 to 100. Unless coarse grains are in excess of 30 percent their influence is not great.

The permeability of a sand, as previously stated, varies with the amount of moisture added, but this in turn varies with the grain fineness and the percent of A.F.A. clay, as shown in table 7.

It so happens that the optimum moisture content for the three sands in table 7 is the same, but this is not true for all sands. Material with a moderately large percentage of moisture tends to have an increased permeability when baked. This is because voids are left by the evaporation of the moisture.

Effect of Ramming

Too soft ramming produces a decrease in mold hardness and an increase in permeability, and may result in swells and strains in the mold. Heavily tempered or wet sand rams or packs closely, and has lower permeability. A properly tempered molding sand when rammed must have sufficient permeability to permit the passage of gases and vapors generated when the mold is in contact with the hot metal; otherwise scabs or blow holes are produced in the metal.

Reichert states that for each cubic inch of sand dried, approximately 27 cubic inches of water vapor is generated for each percent moisture in the sand. Thus a sand with 7 percent moisture would give off 190 cubic inches of water vapor for each cubic inch of sand dried. This water vapor will tend to set up a back pressure against the metal and interfere with the production of sound castings. Provisions must, therefore, be made for the escape of this vapor.

Briggs says that steel-molding sand should have a permeability greater than 75.[29] Brass sands should have a low green permeability. If moisture is kept at a minimum and gas-forming binders eliminated, sand of lower permeability can be used. Backing sand should have higher permeability than facing sand.

[29] Briggs, C. W., The metallurgy of steel castings, 1st ed., New York, McGraw-Hill Book Co., Inc., 1946.

Permeability should be controlled. Very low permeability produces blows, cuts, and scabs; too high permeability allows metal to penetrate between sand grains, resulting in a rough finish on the casting.

Hot Permeability[30]

Hot permeability is the permeability of sand at mold temperature. As the temperature increases, the permeability, though relatively low at first, increases slightly and then falls off. Saunders[31] states that around 200° centigrade (392° fahrenheit) the permeability is low; it increases at 300° centigrade (570° fahrenheit) and falls to a low at 1000° centigrade (1800° fahrenheit). On cooling, the curves are smoother, and the permeability decreases gradually to around 600° centigrade, after which it increases to room temperature. With sand alone the permeability curves for heating and cooling are practically the same.

When metal is poured into the mold, the water in the sand next to the metal is converted into steam and superheated. In addition, gas may be formed by combustion of organic matter. There should be enough permeability to allow for the escape of all vapors and gases.

Hudson has also pointed out[32] that the expansion of the air in the sand resulting from heating is a powerful factor in cutting down permeability. To illustrate this, he used a 1/16-inch vitreosil tube which had a permeability of 22. At 1000° centigrade this permeability was reduced to 3 as a result of expansion of the air.

Another factor that determines hot permeability is the expansion of quartz when heated. Expansion is appreciable up to 575° centigrade, causing a relative decrease in pore space; but between 575° and 1250° centigrade, expansion is negligible.

MOLD HARDNESS[33]

With constant ramming, mold hardness increases with the green strength of the sand. It decreases with increase in moisture beyond the well-tempered range and increases slowly with an increase in fineness of the sand. The mold hardness of a bentonite-bonded synthetic mixture slowly increases as the moisture increases.

There is no A.F.A. test to correlate mold hardness and ability to resist erosion or spalling. Caine states[34] that high dry hardness is beneficial in eliminating washed sand, "but if this value is raised too much, the accompanying high dry strength may cause a serious cracking problem."

STRENGTH OF SANDS

Three types of strength, compressive, shear, and tensile, are recognized. The value of each represents the maximum strength which a given sand is capable of developing when subjected to the respective compres-

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[30] Briggs, C. W., idem.
Hudson, F., Some properties of mold and core materials at elevated temperatures: Foundry Trade Jour., Dec. 5, 1935, pp. 411-416.
Saunders, W. M., and Saunders, W. M. Jr., Effect of heat on the permeability of natural molding sands: Am. Foundrymen's Assoc. Trans., vol. 38, p. 259, 1930.

[31] Saunders and Saunders, op. cit.

[32] Op. cit.

[33] Dietert, H. W., Control of mold hardness and other properties: Am. Foundrymen's Assoc. Trans., vol. 40, p. 63, 1932.

[34] Caine, J. B., Effect of cereal binders on the physical properties of synthetic sands at room temperatures: Steel Foundry Facts, no. 8, March 1941.

sive, shear, and tensile stresses. These several types of strength may be determined on either the green sand as used for molding, or on the sand which has been dried at 221 to 230° fahrenheit (105 to 110° centigrade).

To determine hot compressive strength, the compressive-strength test is applied to sands at high temperatures.

Bond strength depends on both internal and external factors. Internal factors are quantity and quality of clay present, amount of moisture in the sand, distribution of clay in the sand mixture, amount of non-plastic foreign matter such as sea coal, and size and shape of grains. External factors are intensity of mixing, degree of ramming, jolting, or squeezing. No one of these factors is entirely responsible for the development of the maximum bonding strength.

Mulling and Bond Strength

For maximum bond strength the clay should be uniformly mixed with the sand grains, so that the grains become uniformly coated. Increased time of mulling, up to a certain point, tends to increase the completeness of the mixing.

Green Compression Strength

Other things being equal, the green compressive strength of a sand seems directly related to the clay content for any given type of clay. Too widely distributed grain sizes develop higher green compression than narrow grain size distribution. The green compression strength increases as the moisture increases to an optimum. With further addition of water the strength declines (table 6).

According to Davies and Rees,[35] their experiments with synthetic molding sands and core-sand mixtures show that ''for sands having comparable mechanical gradings, the strength of mixtures prepared with angular sands is lower than that of mixtures based on rounded sands, and that the surface friability of the dried mold or core increases with the angularity of the sand.''

The figures in the following table are taken from Davies and Rees. Similar results were obtained by Ries and Lee.[36] Dunbeck, however, holds the opposite view.[37]

The amount of water and hardness of ramming (tables 9, 10) may also have to be considered in determining green compression strength.

The upper half of table 9 gives figures by Dunbeck,[38] which show the effect of moisture in a mixture of 10 percent fire clay and 90 percent silica sand. The lower half of the table gives figures obtained by Grim and Cuthbert for another type of fire clay.

Grim and Cuthbert[39] point out that bonding clays develop the greatest relative difference in maximum strength in sands where the clay content is low; if the clay content is increased the difference in bonding power decreases. In order of ascending maximum strength (in sands containing 4 percent clay) the bonding clays are illite, kaolinite,

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[35] Op. cit.

[36] Ries, H., and Lee, H. V., Relations between shape of grain and strength of sand: Am. Foundrymen's Assoc. Trans., vol. 39, p. 857, 1931.

[37] Dunbeck, N. J., Molds and core materials, Am. Foundrymen's Assoc., Southern California Chapt., February 11, 1946.

[38] Idem.

[39] Grim, R. W., and Cuthbert, L., The bonding action of clays: Illinois Geol. Survey Rept. Inv. 102, pt. 1, 1945.

Table 8. Effect of grain shape on green and dry compressive strength

Sand F (rounded)				
Moisture percent	2.5	3.0	4.0	5.0
Green strength	10.5	7.8	5.8	4.6
Dry strength	34	41	56	70
Sand N (angular)				
Moisture percent	2.5	3.0	4.0	5.0
Green strength	4.8	3.9	2.8	2.0
Dry strength	18	25	38	51

Table 9. Relation of green compressive strength to percentage moisture

Sand A (after Dunbeck)

Water percent	Green compression strength, psi
2	9.36
3	7.98
4	6.41
5	4.88
6	3.75
Sand B (after Grim)	
0.75	11.00
1.00	12.00
1.5	15.00
2.0	18.00
3.0	14.00
4.0	9.00

Table 10. Relation between green compression strength and mold hardness

Number of rams	Green compression, psi	Mold hardness
1	3.3	65
3	6.8	82
9	14.1	92

Table 11. Dry strength for 95 percent sand, 5 percent bentonite, after Morey and Taylor

Percent water content	Dry strength, psi	Percent water content	Dry strength, psi
1.23	----------	4.30	132.6
1.79	66.1	5.41	138.8
2.36	106.5	7.41	168.5
3.45	127.4	9.64	177.5

halloysite, montmorillonite A, and montmorillonite B. The sands containing 8 percent clay show a greater difference in maximum bonding strength between illite- and kaolinite-bearing sands than between halloysite- and montmorillonite B-bearing sands. The peak of the strength curve usually shifts to the right with increasing amounts of clay.

Green strength should be sufficient to permit making of the mold and insure its holding its shape during casting. Each sand mixture has some particular green compressive strength which seems to yield the best results. Scabs, buckles, swells, drops, and cuts are blamed by some on improper bond strength.

Dry Strength

The dry strength of a sand is measured after the sand has been heated to 212° fahrenheit (100° centigrade) for 2 hours and then allowed to cool. The dry strength rises in direct proportion to an increase in the original moisture content (table 11) or the sand fineness.[40] A 120 sand is nearly twice as strong as a 30. With increasing dry strength the mold hardness usually increases.

It is believed that low dry strength may cause an increase in cuts and washes, as well as dirt inclusions. High dry strength may increase rat tails, buckles, pulldowns, and scabs.

Dry strength is increased by[41] (1) longer and more intensive mixing; (2) increasing moisture of green sand; (3) harder ramming (greater hardness); (4) adding more clay and water; (5) adding various binders; and (6) increasing grain-size distribution. Dry strength of fireclay-bonded sand increases with clay content if the moisture is increased. It can be lower or higher than bentonite-bonded sand depending on amount of clay added. Dry strength is important in the production of light castings when surface-casting skin is formed before development of any appreciable hot strength.

Air-Set Strength

Grim and Cuthbert call attention to what they call the air-set strength, which is the strength developed by the sand when it is allowed to stand in the air. This strength increases with the amount of tempering water added to the sand.[42] As shown in table 12,[43] the samples did not lose all their moisture; but the interesting fact is that in these synthetic mixtures the halloysite used developed a higher air-set strength at the end of 3 hours than did any of the other three bond clays.

Tensile Strength

The test for tensile strength is comparatively little used for green sand. This is possibly because it requires a special technique and is troublesome to make. The sand is rammed in a special two-part tube, and the force required to pull it apart is measured in ounces. The test is an important one to make if the sand is to be subjected to tension forces. According to Briggs,[44] the tensile strength of fine sands (A.F.A. grain

[40] Morey, R. E., and Taylor, H. F., Some properties of synthetically bonded steel sands: Am. Foundrymen's Assoc. Trans., vol. 49, p. 388, 1941.
[41] Dunbeck, N. A., How to change the properties of sand: Am. Foundryman, January 1944, pp. 9-12 . . . February 1944, pp. 8-12.
[42] Morey, R. E., and Taylor, H. F., op. cit. (vol. 49).
[43] Grim, R. W., and Cuthbert, L., op. cit.
[44] Briggs, C. W., The metallurgy of steel castings, 1st ed., New York, McGraw-Hill Book Co., Inc., 1946.

Table 12. Air-set strength in pounds per square inch of different clays (after Grim and Cuthbert)

Green compression strength determined immediately after ramming		Compression strength determined the following periods of time after ramming							
		15 minutes		30 minutes		1 hour		3 hours	
Strength	Percent moisture	Strength	Percent moisture	Strength	Percent moisture	Strength	Percent moisture	Strength	Percent moisture
Halloysite clay (12 percent clay mixture)									
7.0	4.75	14.9	4.45	20.8	4.3	31.5	3.82	51.0	2.45
3.0	5.95	4.0	5.7	5.2	5.4	9.5	5.1	52.5	3.95
Kaolinite clay (10 percent clay mixture)									
7.6	3.8	13.2	3.35	17.2	2.95	21.8	2.55	30.0	1.50
4.0	5.2	5.5	4.75	8.0	4.40	13.5	3.7	40.0	1.95
Illite clay (12 percent clay mixture)									
8.5	4.2	12.2	3.65	15.4	3.37	20.4	2.9	32.3	2.05
5.05	5.4	8.5	4.85	11.6	4.47	17.1	3.95	33.3	2.70
Montmorillonite clay IA (6 percent clay mixture)									
7.75	3.2	9.90	2.85	11.0	2.66	15.8	2.3	27.6	1.70
5.87	4.6	7.0	4.3	8.6	4.0	11.3	3.70	22.8	2.9

fineness of 150 or higher) gives "a more nearly correct indication of active clay content than does compression strength, since the fines in the sand create more compression than tensile strength." The tensile test of baked core sands is determined from a test-specimen of the same dimensions and shape as a briquette used in cement testing.

Flowability

The American Foundrymen's Association defines flowability as "the property of a foundry sand mixture which enables it to fill pattern recesses and move in any direction against pattern surfaces under pressure." This is an important property, but there is as yet no standard method for testing it, although several have been suggested.[45]

It is generally believed that flowability is increased by uniform distribution of sand, reduction of clay content, and reduction of fines.

Shear Strength

The green shear strength is not used nearly as much as the green compression, although the American Foundrymen's Association has developed a standard method for testing it.[46]

Some foundries test both the green compression and the green shear, but they do not, as a rule, seem to be able to show that the latter supplies any information not obtainable from the former.

Deformation

Deformation is defined[47] as the change in linear dimension of a sand mixture in response to a stress. Deformation may also be said to indicate the degree of brittleness of the sand. It is an important property[48] which should be given greater attention, but the fact that its determination requires careful manipulation may have interfered with its wider use.

The test is carried out with the aid of a special attachment on the compression machine. Recent improvements in this attachment have greatly increased the reliability of the test.[49] When pressure is applied to the standard 2- by 2-inch test piece, it may be compressed slightly before it fails. The variation in deformation depends on the plasticity of the mixture, which in turn is influenced by the nature of the bonding material in the sand.

The deformation is usually expressed in thousandths of an inch per inch. The product of the green compression and deformation, multiplied by 1000, gives the sand toughness, formerly but incorrectly called resilience. This final product is usually known as the STN, or sand toughness number, and indicates the workability of the sand.

Deformation does not necessarily stand in a constant ratio to green compression, although they are both related to the character and quantity of the bond.

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[45] Chadwick, R., Deformation and flowability tests of molding sands: Foundry Trade Jour., June 6, 1940, p. 416.

Kyle, P. E., Flowability of molding sand: Am. Foundrymen's Assoc. Trans., vol. 48, p. 175, 1940.

Lissell, E. O., and Ash, E. J., A study of the flowability of foundry sands: Am. Foundrymen's Assoc. Trans., vol. 50, p. 637, 1942 . . . Foundry, vol. 78, p. 151, 1942 . . . vol. 80, p. 151, 1942.

[46] Handbook of testing sands and clays, 5th ed., Am. Foundrymen's Assoc., 1945.

[47] Handbook of testing sands and clays, 5th ed., Am. Foundrymen's Assoc., 1945.

[48] Buchanan, W. V., Sand testing, with special reference to deformation: Foundry Trade Jour., March 1940, p. 199.

Parker, W. G., Green deformation and sand toughness: Am. Foundryman, January 1946.

[49] Parker, W. G., Green deformation and sand toughness: Am. Foundryman, January, 1946.

Table 13. Green compression, deformation, and STN

Sand	Percent moisture	Green compression strength, psi	Green permeability	Deformation in in/2 in.	STN
Case 1 { A	4.1	8.1	150	0.015	121
Case 1 { B	4.2	7.3	150	0.030	219
Case 1 { C	5.5	9.4	25	0.014	131
Case 1 { D	6.6	7.7	24	0.017	131

In the two cases of table 13, quoted from Parker,[50] sand A of case 1 has only half the deformation value of sand B. The difference in green compression is probably due to differences in the character of the bond, which gives a different deformation and STN.

Case 2 (C and D) shows the same sand with different moisture-contents which cause a difference in green compression, and also a difference in deformation. The STN, however, is the same in both. As a good example of how deformation can be used, we quote from one operator, who writes:

"We compound a sand mixture which gives us the desired results in the foundry. When this mixture is put into use we determine within what range the deformation values may vary and still give us satisfactory results in molding. When we run into difficulties in drawing the pattern from the mold, we find the low limit of deformation; on the other hand, when the sand becomes low in flowability and does not ram to a sufficiently tight mold surface, we reach the upper limit of deformation. This variation is usually held within 0.010 inch per inch. We then control the deformation by variations in moisture or cereal binder. While determining these standards, of course, we maintain our green compression strength as nearly uniform as possible.

"The principal value of the deformation test here has been in the control of the workability of sands. We have not, as yet, been able to correlate any casting defects, except those dependent on sand workability, with deformation.

"We have, also, found it helpful in controlling sand mixes; that is, when the sand mill operators add more or less binders than the amount set up for a sand mixture, it is often reflected in the deformation test. We have operators prone to throw additional binders into a batch of sand in order to cut down on the milling cycle. Checks on sand deformation have helped us to overcome this tendency."

Dietert and Woodliff [51] give the following sand toughness numbers for different mixtures:

	STN
Ferrous and non-ferrous sands with sea coal	60-130
Gray iron and malleable sands with sea coal	70-130
Clay, bentonite, cereal-bonded steel green sands	80-170
Skin or oven-dried molds, steel sands	150-230

Above the upper limits of each group, there may be danger of scabs, buckles, or blows; and below the lower limits there is danger of cutting, drops, rat tails, and mold peeling.

PROPERTIES OF SANDS AT ELEVATED TEMPERATURES

The sand properties previously described are those existing at room temperature. Since, however, both molds and cores are subjected to elevated temperatures in casting, it is important to know how sands behave at such temperatures. A number of tests have been tried, but they have not as yet been standardized, and caution should be exercised until the conditions they have to meet have been determined.

[50] Op. cit.
[51] Dietert, H. W., and Woodliff, E. E., Measuring deformation of molding sand: Foundry, vol. 67, p. 28, 1939.

A number of foundries, however, use these tests for expansion, hot compressive strength, durability, collapsibility, and heat shock, although foundrymen are not unanimous in their opinion of their value. One person may approve of the hot strength test and place no value on the expansion test, while another may hold the opposite view. Nor are all foundries equipped to make these tests.

While definite instructions may be given for making these tests the interpretation of the data obtained must be left to the individual foundryman. Thus he may find that certain defects develop in the mold when the test specimen indicates a certain hot compressive strength, expansion, or collapsibility. Changing the mixture may correct these defects and this may be reflected in a change in the laboratory test values. Theoretically, then, these new values should be maintained to avoid defects due to the sand. Since there is no definite temperature at which the tests are made, and no definite specimen-exposure time, these must be regulated to meet the needs of the individual foundry.

When testing conditions have been properly standardized and there is a better knowledge of the significance of elevated temperature tests it is likely that they will be more widely used.

Hot Compressive Strength

In making the hot compressive-strength test, the specimen is placed in a hot furnace and left for a variable period of time, usually from 2 to 12 minutes, before pressure is applied. The hot compressive strength for clay-bonded mixtures usually rises with an increase in temperature, until a maximum is reached about 2000° fahrenheit, (or sometimes less), after which with further temperature increase, the strength decreases.[52] There are some exceptions to this rule.

Different mixtures and different bonding clays show different hot strengths, and the time of exposure to a given temperature may also affect the results. At 2500° fahrenheit the hot compression strength for all bonds seems to be greatest at 2 minutes; but at 1600° fahrenheit, the strength appears to increase with time of soaking.

Western bentonite develops higher hot strength than southern bentonite or fire clay. According to the experiments of D. C. Williams, 4 percent western bentonite may even develop more hot compressive strength than 10 percent fire clay, but the maximum points are not necessarily at the same temperature when based on 20 minutes exposure to heat. The hot compressive strengths also seem to vary with the amount of moisture in the original mixture.

The strength of 10 percent illite approaches that of a like amount of fire clay with 5 percent moisture, but not with 3 percent moisture. Halloysite showed little hot compressive strength even up to 2500° fahrenheit.

The addition of silica flour raises the hot compressive strength. Some writers [53] claim that secondary peaks of strength are developed when silica flour is present.

One of the difficulties in hot strength testing is in getting results that check, although at 2500° fahrenheit this seems easier than at lower temperatures.[54] Hot strength tests are usually made on $1\frac{1}{8}$- by 2-inch speci-

[52] York, H. L., Report of progress of sand research on steel sand mixtures at elevated temperatures: Am. Foundrymen's Assoc. Trans., vol. 47, p. 809, 1939.

[53] Dietert, H. W., Doelman, R. L., and Bennett, R. W., Mold surface properties at elevated temperatures: Am. Foundrymen's Assoc. Trans., vol. 52, p. 421, 1944.

[54] Rassenfoss, J. A., Reproducibility of elevated temperature sand test results: Am. Foundrymen's Assoc. Trans., vol. 52, p. 711, 1944.

mens. Nothing has been published on the relationship between $1\frac{1}{8}$- by 2-inch and 2- by 2-inch specimens at elevated temperatures. It should also be added that the entire test specimen does not heat through rapidly; and when held at a given temperature, it may take some minutes for the center to reach the same temperature as the exterior.

Replies to an inquiry addressed to a number of foundries using the hot compressive-strength test indicate that few of them use the test for daily testing, but more for research. The time of soaking after the specimen has reached the furnace temperature varies usually from 2 to 12 minutes, depending on what the foundryman considers gives him the best information. Attempts are made by many to correlate the results with the quality of the casting. If the casting results are not satisfactory, the mixture can be changed, and the properties determined for the one that gives good results.

As one interesting example, the experiments of A. Satz [55] are cited. He found that it was possible to correlate the behavior of the sand in the hot strength test with that in the mold. Cracking and spalling tended to indicate that the sand would not behave properly, and accordingly, changes were made in the mixture.

Satz also found that within a certain hot strength range good castings were produced. If the hot strength fell below the acceptable range, the castings showed dirt; and, if they rose above this range, scabs or dirt were encountered. The mixture could then be changed.

Caine Elevated Temperature Test.[56] A test recently recommended by J. B. Caine consists in exposing 2- by 2-inch specimens to the radiant heat of molten metal, or partly immersing them in molten metal. It is claimed that the effects produced in the sand are similar to those developed when the metal is cast in the sand mold.

Expansion and Contraction

Sand grains expand on heating, but clay contracts. When a bonded sand is heated it begins to expand, but with continued heating it contracts. When allowed to cool to room temperature, it contracts still further.

As pointed out in the section on hot permeability, sand expands appreciably up to about 1079° fahrenheit (575° centigrade), and in most hot expansion tests the sand expands for a period and then begins to contract. This contraction may be influenced by the fire shrinkage of the clay bond, which may be sufficient to counteract any further expansion of the sand grains.

Therefore, a sand of low clay content may be expected to show higher expansion than a sand of high clay content. Furthermore, the lower the refractoriness of the clay bond the less may be the expansion of the sand mixture.

A uniform-grained sand is claimed to have higher expansion than a sand with a wide size frequency range.

Expansion and contraction may be tested in several different ways, which might be designated as free, partially restrained, and restrained expansion.

[55] Satz, A., Elevated temperature tests in sand control: Am. Foundryman, June 1945, p. 55.

[56] Caine, J. B., A study of the behavior of molding sand in contact with liquid steel: Steel Foundry Facts, no. 69, p. 2, 1947 ... Foundry, July 1947.

In the free expansion test the cathetometer method [57] is used. Sights are taken on targets at the top and bottom of the specimen during heating. The specimen itself is free in the furnace and there is no pressure on it.

In the partially restrained expansion test, the specimen is set in the furnace on a disc, with another disc on top. A fused quartz rod rests on the upper disc and the pressure of the rod can be regulated. The upper end of the rod is in contact with a dial gage which measures the amount of expansion and contraction. Although the pressure of this rod may be only 4 or 5 ounces, it may nevertheless have an effect on the contraction when the bond becomes soft. This is shown by a comparison of specimens tested under partially restrained expansion conditions with specimens tested under conditions of free expansion.

In the restrained expansion test, the sand specimen is confined in a fused quartz tube.[58] It is supported at one end and free to expand at the other. A fused quartz rod is pressed against a disc covering the free end, while the other end of the rod is in contact with a registering dial. In the opinion of some, these conditions duplicate more nearly the conditions met in actual practice, where the sand is confined in the mold.

Expansion and contraction during heating are blamed by some writers for various casting defects, such as scabs, buckles, and rat tails. For example, the facing sand may reach the temperature at which it begins to contract, while the backing sand is still expanding and pushing against the facing. This may cause it to crack, and may even break the skin on the casting.

Buchanan, however, disputes this, and thinks that scabs are caused by steam pressure from the moisture, which pushes sand into the metal. If so, higher permeability might prevent it.

Dietert claims that confined expansion is reduced by: (1) increasing grain size; (2) reducing fines; (3) adding combustibles; (4) reducing mold hardness; (5) increasing permeability; (6) reducing moisture; (7) adding silica flour.

Dunbeck [59] suggests the following cures: (1) Faster pouring, permitting casting to set before mold face can break; (2) softer ramming, thus allowing space for expansion without breaking mold face; (3) reducing flowability so as to give softer mold face.

Core Collapsibility

When cores are surrounded by metal, the latter on shrinking applies pressure to the core. If the core is too rigid, and maintains its strength, it may develop hot tears or strains in the casting.

A sufficient portion of a core, therefore, should lose its strength in part, at least, and collapse after the metal has begun to harden. If it is too weak, and collapses too soon, core washing may result.

In order to test core collapsibility the test specimen is placed in a testing furnace and subjected to a pre-determined load of perhaps 50 pounds. The time is noted that the core can sustain this load without collapsing. Different mixtures show different periods of collapsing time when tested. According to the American Foundrymen's Association

[57] Ehrhardt, G. W., Measurement of free expansion of sand mixtures at high temperatures: Am. Foundrymen's Assoc. Trans., vol. 49, p. 640, 1941.
[58] Dietert, Dolman, and Bennett, op. cit.
Hudson, F., op. cit.
[59] Dunbeck, N. J., Molds and core materials, Am. Foundrymen's Assoc., Southern California Chapt., February 11, 1946.

Committee on Testing Core Mixtures in Their Own Atmosphere, they usually show a lower collapsibility than when tested in the atmosphere of the testing furnace.

Heat-Shock Test

In the heat-shock test, the test piece is placed in the hot furnace for about 3 minutes. If the specimen cracks or spalls inside, some foundrymen feel that the mixture tested will not work well for large castings.

Such a test could probably be made just as well in a small muffle furnace as in a larger and more expensive one adapted to other elevated temperature tests.

Durability

The American Foundrymen's Association defines durability as the rate of deterioration of a sand in use due to dehydration of its contained clay. It might, and probably does, involve some vitrification of the clay close to the mold face, accompanied by an agglomeration of the particles. In any event, it results in a loss of green strength, and to keep the sand up to its original condition, more bond must be added. A sand of high durability could be used over a number of times without showing serious loss of strength.

Covan [60] found that naturally bonded sands have a lower durability than synthetic sands. If the durability is too low it also tends to reduce the permeability, and more tempering water is required. If sands are bonded with kaolinite or illite, the larger aggregates of these minerals tend to be broken up each time the sand is mulled; this helps to keep up the strength of the sand.[61]

Up to the present time, no standard method for testing the durability of a sand has been adopted. Several methods have been tried, among which are the repeated-pour test, the oven test, and the rehydration test.

Repeated-Pour Test. This consists in pouring small test molds. After each pour test the sand is retempered with the addition of nothing but water. The loss of strength is determined after each pour.

Oven Test. A sample of the sand is heated at 800° fahrenheit for 2 hours. It is cooled to room temperature, retempered, and its strength tested. The sand is then heated to successively higher temperatures, at intervals of 200° fahrenheit, up to 1400° fahrenheit and its strength tested after each heating.

Rehydration Test. By this method a sample of sand is dried to a constant weight at 105° centigrade and weighed. It is then heated sufficiently to dehydrate the clay, cooled in a desiccator, and weighed again. The sample is then covered with water for 12 hours after which it is heated again at 105° centigrade to a constant weight, cooled in desiccator and weighed. The increase in weight after the higher heating represents the water of rehydration.

Temperature of Molds

The entire mold face approaches the temperature of the molten metal in contact with it; but as the distance from the mold face increases, the temperature drops.

[60] Covan, J., Comparison data on the durability of naturally bonded and synthetic molding sands by the repeated pour test: Am. Foundrymen's Assoc. Trans., vol. 50, p. 539, 1942.

[61] Grim and Cuthbert, op. cit.

Various figures illustrating this have been published.[62] According to Briggs [63] the clay bond in many cases may be permanently altered for a distance of 1 to 2 inches from the mold face, but the distance to which this change occurs will depend on the size of the casting and the heat content of the metal.

Sintering Point

Sintering point is defined as the temperature at which the molding material begins to adhere to the casting, or, in the laboratory, the temperature at which the sand adheres to a platinum ribbon.[64] In other words, the temperature at which incipient fusion occurs is determined. In this process, two stages are recognized: (1) The "A" point—when the coating on the sand grains has sintered and softened enough to adhere to a platinum ribbon with sufficient force to bend it when lifted; (2) the "B" point—at which the smaller grains are fused and the energy required to remove the adhering ribbon increases rapidly. This represents the point of incipient fusion of the sand grains as a whole.[65]

The best steel sands are those which have the right amount of bond to cement sand particles and fuse to a mass that is easily cleaned off. Sintering point increases with grain size. It decreases also "with increasing amounts of natural and added bond." For steel sands it is 2450 to 2650° fahrenheit for A point, 2600 to 2750° fahrenheit for B point. Fire-clay bonded washed silica sand usually has a higher B point than bentonite-bonded sand.

Caine [66] says kaolin and bentonite in 5 percent amounts lower B point 130 to 160° fahrenheit, the kaolin reducing it the lesser amount.

If the sand has a high sintering point, it is supposed to be more easily removed from the casting.

SAND CONTROL

Many foundries have sand-testing laboratories in which they can test sands delivered to them by the sand producers, as well as the mixtures that are used in the foundry. The latter should be tested at regular intervals in order to determine whether the mold and core mixtures used in the foundry are running uniform.

A careful check should also be made between the laboratory tests and the results obtained in the foundry, so that if the castings show defects due to the sand the mixture can be changed. Unfortunately in some foundries there is not enough cooperation between the sand-testing laboratory and the foundry. There is no sense in making the tests, recording them in a book and doing nothing further. In addition to testing sands, the laboratory can also be used to test various binders, bond clays, and washes.

Equipment Required

A well-equipped sand-testing laboratory will usually have the following equipment:

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[62] Briggs, C. W., and Gezelius, R. A., Studies on solidification and contraction in steel castings: Am. Foundrymen's Assoc. Trans., vol. 43, p. 274, 1935.
Dierker, A. H., Reclaiming steel-foundry sands: Am. Inst. Min. Met. Eng. Tech. Pub. 261, 1930.

[63] Op. cit.

[64] Handbook of testing sands and clays, 5th ed., Am. Foundrymen's Assoc., 1945.

[65] Caine, J. B., Report of Subcommittee on Sintering Test, Foundry Sand Research Committee, 1941-42: Am. Foundrymen's Assoc. Trans., vol. 50, 1942.

[66] Caine, J. B., A study of the behavior of molding sand in contact with liquid steel: Steel Foundry Facts, no. 69, p. 2, 1947 . . . Foundry, July 1947.

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1. Apparatus for making fineness test of sand, which includes:
   a. Vibrating apparatus with timing device for sieve test.
   b. Set of 8-inch half-height sieves.
   c. Balance to weigh sand retained on each sieve.
   d. In case of sand containing clay, a disintegrating jar.
   e. Hydrometer, if it is desired, to separate the A. F. A. clay into its constituent parts.
2. Drying oven or some other apparatus for determining moisture in sand, capable of attaining temperature of 350° fahrenheit.
3. Laboratory muller for mixing sand with the desired amount of moisture, or sand and clay in the case of synthetic sands. A 24-inch muller is desirable.
4. Gallon jars for holding prepared samples, or samples taken from the foundry.
5. Rammer for making 2- by 2-inch test specimens. This should preferably be attached to a firm base, such as a concrete post.
6. Permeability apparatus.
7. Compression apparatus.
8. Attachments for making deformation and tensile tests.
9. Hardness tester.
10. Rammer for making 1⅛- by 2-inch specimens, and split specimen tube in which to make them.
11. A furnace in which the test specimen can be heated to the desired temperature, and in which tests can be made for hot compressive strength, core collapsibility, expansion and contraction, and spalling.
12. A core-baking oven with a maximum working temperature of 550° fahrenheit.

Items 1 to 8 inclusive are used for testing green or dried specimens. For making tests of samples at elevated temperatures, items 10 to 12 are needed. The elevated-temperature tests have not yet been standardized and are not yet widely used or thoroughly understood by all foundrymen.

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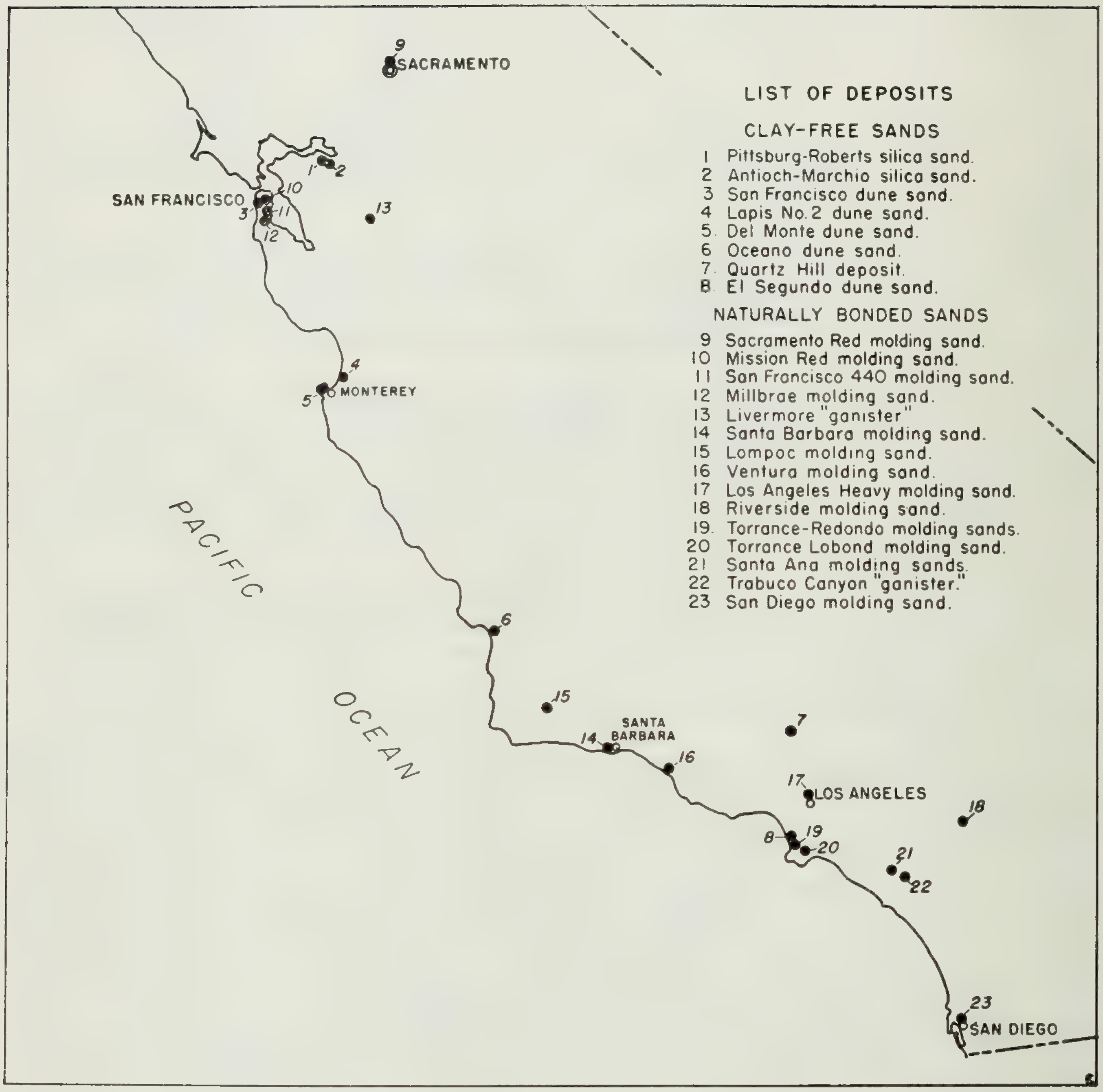

FIGURE 1. Index map of coastal region of part of California showing foundry-sand localities.

CALIFORNIA FOUNDRY SANDS *

By Lauren A. Wright **

OUTLINE OF REPORT

* Fifteen years ago, at the suggestion of Olaf P. Jenkins, then Chief Geologist of the California State Division of Mines, a geological study of the sands of California was started by E. Wayne Galliher, at that time associated with the Division. The final results of Dr. Galliher's investigation were never published; however, as indicated in a footnote to a short but very interesting paper in Rock Products, vol. 37, no. 3, pp. 50-51 (*Evolution of Sand Deposits One Factor Often Overlooked—The Character of the Sand Grains—Notes on Purification of Glass Sand,* by E. Wayne Galliher), publication was contemplated. A manuscript copy of an unpublished report, *California Sand Deposits*, which included some 200 pages of text and many illustrations, photographs, charts, and maps, was made available for consultation in the offices of the Division of Mines. This report, prepared in 1932, has formed the background for the inspiration which initiated the preparation of the papers on foundry sands contained in this issue of the *Journal*. The untimely death of Dr. Galliher in 1945 closed the brilliant career of an eminent scholar who unselfishly presented the fruits of his endeavors for our use. *Ed. note, OPJ.*

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ILLUSTRATIONS

ABSTRACT

California is self-sufficient in foundry sands of all general types except high-grade silica sands. Five dune areas along the California coast, at San Francisco, Lapis, Del Monte (Moss Beach), Oceano Beach, and El Segundo Beach, are contributing clay-free feldspathic sands. These sands are suitable for iron and non-ferrous metal casting and are used both as bases for synthetic sands and in cores.

Three foundry sands produced in California have silica contents high enough to meet steel-casting requirements. Two of these are obtained from the Eocene sediments west of Mount Diablo in Contra Costa County; the third is a machine-crushed silica rock from a deposit near Montrose in southern California.

Relatively coarse or "heavy" naturally bonded sands are obtained from alluvial deposits in the San Francisco, Sacramento, Los Angeles, Torrance-Redondo, and Santa Ana areas. These are used principally in heavy iron casting.

Sources of fine-grained or "light" naturally bonded molding sands occur in marine sediments near Millbrae, Lompoc, Goleta, Santa Ana, and Ventura, and in an alluvial deposit near Riverside. Their principal applications are in light iron and non-ferrous work.

Two natural mixtures of refractory clay and high-silica sand, misnamed "ganisters," are used as patching materials and, to a lesser degree, in synthetic sand mixes. Both are from Eocene sediments, one from the Livermore area, the other from the vicinity of Trabuco Canyon in the Santa Ana Mountains.

INTRODUCTION

The statewide foundry industry of California, with its substantial production of iron, steel, and non-ferrous metal castings, has, since its inception, drawn heavily on sands produced in the state. Consequently, the growth of a modest, but increasingly important foundry-sand industry has paralleled that of the foundries themselves. At present, the yearly production of California foundry sands is in the neighborhood of 90,000

tons. This tonnage is divided between clay-free sands and naturally bonded sands in the approximate ratio of three to two.

The clay-free sands currently produced in California are of the following three geologic types: (1) unconsolidated feldspathic sands, some of which contain abundant dark rock and mineral fragments, which are removed from a number of excavations in the dunes of the California coast; (2) high-silica sands as represented by beds in the Eocene sediments north and east of Mount Diablo in central California; and (3) another type of high-silica ''sand'' which is actually a processed, massive quartzitic rock produced from a single deposit in Los Angeles County.

Clay-free foundry sands have in the past been obtained from several of the numerous quarries in partly consolidated feldspathic sandstone. These sands, however, contain silty fractions which, to meet foundry specifications, must be removed by washing. The partly consolidated feldspathic sands, when washed, are commonly similar to the coastal dune sands, but at present are not in general use as foundry materials.

Eight sources of California clay-free sands are now supplying foundries. At two of these, the Del Monte and Lapis dune deposits, foundries consume but a small part of the total output of sand.

About 20 deposits of naturally bonded sands are now actively worked. These are, for the most part, small-scale operations, though some have been in continuous production for nearly 30 years. Others have been short lived. The introduction of new naturally bonded sands markedly increased during World War II.

The author purposes only to outline the occurrences and characteristics of California sands in current or recent use. Brief visits to each of the active properties were attempted in a survey that precluded detailed study. The space allotted each deposit reflects the available information rather than its importance in the industry. A booklet entitled *Foundry Sands and Mold Materials, Report Number Two,* written and published in 1945 by the Northern California Chapter of the American Foundrymen's Association, proved a valuable guide and has been liberally quoted. Much material has also been supplied by men closely affiliated with the foundry industry.

Several of the screen analyses were kindly submitted by H. Ries, who was associated with the project in an advisory capacity, made many valuable suggestions, and accompanied the author on visits to several of the deposits; but most of the analyses were supplied by the producers. The analyses are representative, and other samples from the same deposits may deviate from those shown by several percent.

Among those who generously supplied data or information are Harry E. Blood, Harry E. Blood Company; E. H. Brumley, W. A. Dewhurst, H. M. Donaldson, and L. O. Hofstetter, Brumley-Donaldson Company; D. A. Cannon, Cannon Brick Company; W. R. Magoffin, Caswell and Company; O. D. Sisson and P. C. Valentine, Del Monte Properties Company; H. E. Guiton, Guiton Molding Sand Company; J. J. Gallagher, Daniel Gallagher Company; S. L. Gillan; G. E. Gordon, Gordon Transfer Company; A. M. Ruis, H. M. Hubbard Molding Sand Company; M. J. Marchio, Marchio Sand Company; O. E. Miller and R. G. Miller, Miller Brothers Trucking Company; E. L. Howard and R. B. Roberts, Pacific Coast Aggregates, Inc.; Peter Bugni, Arthur Latham, and T. H. Word, Roberts Sand Company; D. L. Mason, Stanford University; G. G.

Sanders, Tesla Clay and Sand Company; O. D. Messmore, Ventura Molding Sand Company; and H. L. Westlake, Westlake and Sons Company.

GENERAL GEOLOGY

California foundry sands, when classified according to physical properties and uses, with few exceptions, fall into natural geologic subdivisions. The high-silica sands and so-called ''ganisters'' were transported and deposited under the warm, moist climatic conditions of Eocene time. The ''light,'' naturally bonded sands characteristically occur as Pliocene or Pleistocene marine beds. All of the ''heavy'' naturally bonded sands are subaerial Quaternary sediments. The feldspathic, clay-free sands are obtained from Recent beach or near-shore dune deposits.

The alluvial, light Riverside sand and the crushed, quartzitic, high-silica ''sand'' of the Quartz Hill deposit near Montrose are exceptions to these generalizations.

Partly consolidated Eocene feldspathic sands such as those produced from excavations near Corona and Oceanside formerly were used, in part, as foundry sands but are not now marketed for this purpose.[1]

As yet no high-grade silica sand has been produced in California. The previously mentioned silica sands, however, have an average silica content approximating 95 percent and are adequate for use in steel foundries. The other clay-free sands, as well as the naturally bonded sands, are more feldspathic and, consequently, less refractory.

CLAY-FREE SANDS

Contra Costa County

Antioch-Marchio Sand. The Marchio deposit has been developed in recent years, but occurs in a belt of middle Eocene sandstones and shales that has long been a source of high-silica foundry and glass sand.

The Antioch-Marchio sand is produced and processed by M. J. Marchio of Antioch and is obtained from an excavation 7.9 miles south of Antioch by way of Oil Canyon Road.

The excavation is in the lower portion of a clifflike massive sandstone of which a total thickness of approximately 80 feet is exposed. The sandstone, though resistant, is friable and is a portion of a section of alternating sandstone and shaly beds that strikes N. 50° W. and dips 25° NE. When visited, the excavation had uncovered a 40-foot face (pl. 2*A*). The sand is predominantly white but is locally iron-stained in thin layers, parallel with the bedding or adjacent to fractures. The mineral composition appears uniform, but the sandstone is crudely stratified in massive layers of contrasting grain size.

Three grades, coarse, medium, and fine, are recognized by the operator. The medium grade is mined selectively for foundry use and is the sand represented by the analysis in table 1. The coarse-grained sand lies mainly beneath the excavation floor and, in a general way, marks the footwall of the foundry sand portion of the deposit. The fine-grained material occurs as layers several feet thick, the removal of which has thus far been avoided by benching. The operator, however, eventually plans to market all grades throughout the entire sandstone thickness.

[1] The deposit southeast of Corona is now operated by the Owens-Illinois Glass Company, and its output is consumed entirely in glass manufacture.

The material is removed by shooting, is placed on trucks by a caterpillar-type loader, and hauled to a processing plant 3.7 miles to the north (pl. 2*B*). Here it is hydraulically disintegrated and fed through a drum-type rotary scrubber and 8-mesh classifier. The fines are floated off by an adjustable hydraulic current. The processed sand is then moved by a drag to a conveyor belt and is stored in drainage bins prior to shipment.

The marketed product is reported to average 94 to 95 percent silica. There is little specific information available on the adaptability of this sand. Like other sands from the area, it is used as a base for synthetic sands in iron work and its silica content is sufficiently high for steel casting.

The following mineralogic analysis of a sample of Antioch-Marchio sand (table 1) was made by Jewell J. Glass of the United States Geological Survey.[2]

Miss Glass reports:

> "Cursory observation on immersion mounts under the microscope indicates that the coarser portion contains the higher ratio of quartz and that in the middle-sized portion, the ratio of feldspar to quartz increases."

[2] Unpublished analysis.

Table 1. Mineralogic analysis of medium-grade Antioch-Marchio sand.
(Analysis by Jewell J. Glass, U. S. Geological Survey)

Minerals	Approximate percentage by grain count
Quartz	75
Potash feldspar, mostly orthoclase, some microcline	15
Kaolinite and shale fragments	10
Barite	Less than 0.5
Garnet	
Black tourmaline	
Zircon	
Epidote	

Table 2. Sieve analyses, medium- and fine-grade Antioch-Marchio sands.
(Analyses by H. Ries)

Sieve size	Medium		Fine	
	Percent retained	Cumulative percent	Percent retained	Cumulative percent
On 20	.4	.4	.8	.8
40	25.8	26.2	6.0	6.8
50	19.1	45.3	6.4	13.2
70	16.2	61.5	17.2	30.4
100	17.5	79.0	35.4	65.8
140	11.0	90.0	23.0	88.8
200	4.0	94.0	6.0	94.8
270	.8	94.8	.6	95.4
Pan	2.4	97.2	1.9	97.3
Clay	2.0	99.2	2.0	99.3
A.F.A. fineness number	63		78	

Pittsburg-Roberts Sand. The Nortonville-Somersville area, about 5 airline miles south of Pittsburg, has long been California's principal source of high-silica foundry sand. The only current producer is the Roberts Sand Company which is removing sand from the underground workings of the old Nortonville coal mine.

The sand occurs in a continuation of the same Eocene belt from which the Antioch-Marchio sand is produced, about 3½ miles to the southeast. It occurs in two sandstone members of a section of alternating sandstones and shales, striking approximately west and dipping 25° N. The producing layers are each about 25 feet thick and are separated by several tens of feet of shaly beds. The sandstones appear uniform in grain size and mineral composition and reportedly are persistent for several thousand feet. The previously quoted mineralogical analysis of the Marchio material would probably apply, in a general way, to the Roberts sand. The silica content of the marketed sand, according to the operators, ranges from 93 to 98 percent, and an attempt is made to keep this content above 95 percent.

The sand is mined by drifts and overhand stopes. Though friable, it is broken away by shooting. It is trucked to a plant in Pittsburg (pl. 3*A*) where it is first crushed then run through a scrubber in which it passes successively one-half and one-eighth inch screens. It is next classified hydraulically; the fines are carried away, and the remaining sand is partially dewatered with a vacuum dryer. The plant was last visited previous to the installation of a Dorr classifier capable of separating four size ranges. With these grades the operators planned to produce sands blended to individual foundry specifications.

> "This (Pittsburg-Roberts) sand is being used in steel foundries and also as a base for synthetic sand in iron. The silica content is sufficiently high for steel, but it is generally agreed that it is just about on the borderline. It exhibits a tendency to burn in, on heavy filleted sections. It likewise breaks down fairly rapidly on repeated use. . . . Base permeability will vary from 120 to 130.
>
> "This sand works well on heavy steel, inasmuch as heavy steel generally is not poured in too hot. It also works well on lighter plain carbon steels, but, in most cases heavy facings containing silica flour are used. The flour raises the silica content of the facings and reduces burn-in, thereby improving finish and giving a better peel."[3]

[3] Donaldson, Harris M., and others, Foundry sands and mold materials: Foundrymens Assoc., Northern California Chapt., Rept. 2, p. 131, 1945.

Table 3. Screen analysis, processed Pittsburg-Roberts sand.
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 20	2.3	2.3
30	8.8	11.1
40	15.0	26.1
50	22.8	48.9
70	25.2	74.1
100	18.6	92.7
140	4.5	97.2
200	1.0	98.2
270	.2	98.4
Pan	.5	98.9
A.F.A. fineness number		49

Los Angeles County

El Segundo Beach Sand. Sand from the dunes immediately west of the city of El Segundo has been distributed to foundries in the Los Angeles area for more than 20 years. The sand is produced jointly by El Segundo Foundry Materials and Gordon Transfer Companies of El Segundo. It is highly feldspathic, but no detailed mineralogic data are yet available.

The sand is not obtained from any single excavation but is produced from a number of accessible localities. It is loaded on trucks by power shovel and distributed without further processing.

The characteristics and uses of El Segundo Beach sand appear to be generally comparable to those of the Lapis sand described in a following section. The available grain-size data show substantial percentages retained on the 30- or 40-mesh screens, and the sand is, therefore, used in gray iron cores where a smooth finish is not necessarily required. It is also used to open up heap sands. No base permeability figures are available, but a narrow distribution in the 40- to 70-mesh ranges suggests a high permeability value.

Table 4. Screen analysis, El Segundo beach sand.
(Analysis submitted by G. E. Gordon)

Sieve size	Percent retained	Cumulative percent
On 40	38.0	38.0
60	45.0	83.0
80	12.0	95.0
100	4.8	99.8
—100	.2	100.0
A.F.A. fineness number		45

Quartz Hill Deposit. A high-silica sand, is obtained from a deposit within the Los Angeles city limits immediately west of the city of Montrose. The excavation itself is at the north end of Pali Avenue and north of Honolulu Avenue. The property is operated by S. L. Gillan who is also the distributor.

Actually the deposit is not a sand or sandstone but a large mass of almost pure silica rock in an igneous and metamorphic terrane. This geologic setting is unique among California foundry materials. Cebeci, in a detailed study of the area [4] concluded that most of the silica was quartzitic but that there were smaller amounts of silexite nearby.

The principal silica mass is exposed over an area of about 4½ acres on a low ridge (known locally as Quartz Hill) surrounded by alluvium. An insignificant amount of the available reserves has been removed to date.

The silica rock is highly fractured and can be removed by power shovel without shooting. The material, crushed to meet foundry specifications, must pass the 10-mesh and be retained on the 40-mesh screens. Microscopic fracturing with no preferred orientation assists in this operation and tends to produce equidimensional grains.

[4] Cebeci, Ahmet, A study of quartz deposits near Highway Highlands, Los Angeles County, California, unpublished Master's thesis, California Institute of Technology, 1944.

The product, according to Mr. Gillan, consistently runs 98 percent silica, 1.5 percent alumina, and 0.5 percent iron oxide. The iron oxide prevents use as a glass sand, though part of the output is used in the manufacture of silica brick. The chief application of the sand, however, is as a core material in large steel castings.

Monterey County

Del Monte Sand. The dunes of Moss Beach south of Pacific Grove are the chief Pacific Coast source of core sands for gray iron and non-ferrous casting. These deposits, which have been worked for more than 50 years, are owned and operated by Del Monte Properties Company. The early production was consumed almost entirely as foundry sand, but, though output for this purpose has steadily increased, the glass industry is now the principal consumer. In recent years the consumption of Del Monte sand in glass manufacture has been further increased by the installation of a plant of the Owens-Illinois Glass Company south of the older Del Monte operation.

The sand occurs in three large adjacent dune areas from which only a small portion of the reserves has been removed. The excavated sand is being partly replenished by introduction of new material by wave action.

Del Monte sand is famous for its uniformity of mineral composition and grain-size distribution. Its feldspar content consistently approximates 45 percent, and available analyses indicate an 85 to 95 percent fraction retained in the 40-, 50-, and 70-mesh screens. The operators, however, recognize and selectively remove two grades of sand. These have been designated as "Del Monte" and "Minus 60."

"Del Monte" sand forms the "body" of the dunes, while "Minus 60" is drifted sand naturally classified by wind action and deposited as a layer several feet thick on portions of the dune surface. The only actual physical difference in the two grades is the slightly finer grain size of "Minus 60," a difference caused principally by a paucity of grains retained by the 30-mesh screen. The two sands are mined and processed separately.

All of the crude sand is mechanically loaded on conveyor belts from which it is passed through a 16-mesh screen and is given a light, fresh-water wash. This process removes most of the vegetable contamination. From here, the sand may be conveyed to drainage bins and stockpiled for shipment as "Wet Minus 60" or ordinary "Del Monte." The sand to be dried is run over wet, shaker-type concentrating tables to remove the remaining vegetable impurities and a substantial amount of the dark minerals. Next, it is pumped to a dewatering apparatus or scalper and run through driers of either the steam-jacketed or gas type. Finally, it is passed through a 28-mesh screen, is cooled and placed in storage bins from which it is sacked or shipped in bulk in gondolas or box cars. The final products are known as "Minus 60 Dry" and "Del Monte Special". Material to be used in glass manufacture must be even freer of the dark minerals and is run through a magnetic separator.

"The sand contains a fairly high percentage of feldspar which reduces its refractory values to the point where it cannot be used for steel. However, the silica content—approximately 86 percent—is sufficient to make the material very suitable for iron and non-ferrous work.

"It has proved highly satisfactory for light, medium, and heavy brass, bronze and iron cores. Many foundries find it beneficial to mix Del Monte . . . sand with finer sands to produce tighter cores and thus improve core finish . . .

"Its naturally high permeability—250—makes it readily adaptable to difficult burner core work and jacket cores . . . The sand takes oil readily and good cores are obtained with oil ratios of one to fifty or sixty.

"Among the most recent development of uses for Del Monte . . . sand is its use in blends with naturally bonded sand where an increase in permeability of the naturally bonded sand is desired." [5]

''Minus 60'' has essentially the same uses as ''Del Monte''.

"Where smooth finish in brass, bronze or iron cores is desired, Del Monte Fine Sand (Minus 60) can be used straight or as a core facing. The sand runs uniform and the permeability is sufficiently high to permit its use without danger of either blows or scales. On straight mixes it requires more oil . . . This sand also is used for synthetic sand practice in iron." [6]

The sieve analyses in table 5 are by E. W. Galliher.[7]

Table 5. Sieve analyses, Del Monte and Minus 60 sands.
(Analyses by E. Wayne Galliher)

Sieve size	Del Monte		Minus 60	
	Percent retained	Cumulative percent	Percent retained	Cumulative percent
On 20	1	1		1
30	8	9		----------
40	38	47	5	6
50	35	82	55	60
70	16	98	35	95
100	2	100	5	100
A.F.A. fineness	37		45	
Base permeability tests by D. L. Mason (not of same samples)	210		250	

Lapis No. 2 Sand. The dune sand near Lapis on Monterey Bay has been exploited chiefly as an aggregate material and, to a lesser degree, for a variety of special uses. During World War II, a product from this locality known as Lapis No. 2 was widely used in northern California foundries as a core material for heavy gray iron castings.

The sand is produced by Pacific Coast Aggregates Incorporated, which controls a strip approximately 5 miles long and 1 mile wide bordering the shore line northwest of the town of Marina. Excavations so far have been limited to an area of less than 1 square mile. Within this area the sand is, in general, uniform. Marked local differences in grain size, however, are common and coarseness tends to increase with depth. They are light buff in color and have a relatively high shell-fragment and dark-mineral content. Grains more than 5 millimeters in diameter are present, though sparsely scattered.

[5] Donaldson, Harris M., and others, op. cit., p. 128.
[6] Idem, p. 142.
[7] Galliher. E. W., unpublished manuscript, 1932.

The sand is placed on gondola cars by a rail-mounted clamshell loader (pl. 4*A*). Formerly Lapis No. 2 was distributed undried directly to foundries by rail. Recently, however, Dried Lapis No. 2 has been made available. This material is carried by rail to a plant in Oakland where it is run through a rotary-type gas drier and a 24-mesh screen.

"The silica content (of Lapis No. 2) is sufficient to withstand temperatures for iron and brass, yet not sufficiently high to be used in steel. The best characteristic of Lapis No. 2 is its exceptionally high permeability—475—assuring remarkable venting properties for heavy gray iron cores.

"This sand is used almost exclusively in the production of large gray iron casting cores . . . The sand can also be used to open up heap sand, but would be most beneficial to those heaps producing heavy iron." [8]

Table 6. Sieve analysis, Lapis No. 2
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 20	.7	.7
30	5.6	6.3
40	20.0	26.3
50	41.8	68.1
70	27.0	95.1
100	4.6	99.7
140	.2	99.9
A.F.A. fineness number		41

Table 7. Sieve analysis, Dried Lapis No. 2
(Analysis submitted by Pacific Coast Aggregates, Inc.)

Sieve size	Percent retained	Cumulative percent
On 30	2	2
40	8	10
50	50	60
70	25	85
100	10	95
150	4	99
—150	1	100
A.F.A. fineness number		48

San Francisco County

San Francisco Dune Sand. Dunes near the central portion of San Francisco's western shore supply another sand long used in northern California foundries. Daniel Gallagher Company, the producer, is currently removing material from an excavation in the vicinity of 39th Avenue and Santiago Street (pl. 4*B*).

The sand is distinctly brown, a color resulting chiefly from the dark-mineral content and, to a lesser degree, organic matter. These "impurities," however, do not hinder use of the sand in its relatively unexacting application to core and core-backing work where finish and appearance are of secondary importance.

[8] Donaldson, Harris M., and others, op. cit., p. 129.

The sand is loaded in a bin by a bucket elevator and is trucked to stock piles at the company's warehouse. Considerable care is taken to eliminate the larger vegetable masses as the buckets are loaded.

"Principal users of this dune sand are the San Francisco Bay area brass foundries, who employ it on large core jobs where finish is secondary. For small work, or on jobs where better finish is required, the cores are dipped in a suitable core wash. On large cores where better finish is desired, this sand may be used as a backing sand and the core faced with Oceano, Del Monte fine, or some other cleaner, finer sand.

"The same practice applies for iron. On extremely large iron core jobs, this sand makes up the bulk of the core in order to reduce production costs. A thin facing of Del Monte Fine, Nevada Fire Valley or Oceano will give the desired finish." [9]

Table 8. Sieve analysis, San Francisco Dune sand.
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 20	.1	.1
30	.1	.2
40	1.4	1.6
50	8.6	10.2
70	35.8	46.0
100	40.1	86.1
140	12.4	98.5
200	1.2	99.7
A.F.A. fineness number		64
Base permeability		125

San Luis Obispo County

Oceano Beach Sand. Oceano Beach sand, an unusually uniform and fine-grained material, is produced by Harold E. Guiton from the extensive dunes in the vicinity of Oceano. Mr. Guiton formerly marketed sand from a 70-acre dune just south of town. Present production, however, is obtained from a 100-acre area that begins 1,000 feet east of the shore and borders the north side of Roosevelt Drive for a distance of several blocks. The southern deposit, according to Mr. Guiton, is slightly coarser. The sand obtained from either of the two areas is reported to be consistently uniform. Analyses of an Oceano Beach sand show that 90 percent of the grains are retained on either the 100- or 140-mesh screen.

The sand is excavated with a mechanical loader (pl. 5*A*), and is trucked directly to gondolas on a nearby rail siding. Neither washing nor screening is necessary. The operator formerly employed a storage shed to assure a relatively dry product in the winter months. The shed is no longer used, but the installation of a dryer is contemplated.

"This (Oceano Beach sand) might also be called a flexible sand because it can be used for so many purposes. It is clean enough and also high enough in silica to be adaptable for magnesium cores or molding sand. It also is used to a great extent in light cores for brass, bronze, and aluminum. One of its most recent uses is in synthetic sand practice for light and medium iron molding. The chief advantage of this sand is its very close natural grain distribution . . . which accounts for its remarkable base permeability of 85 . . . It is possible with this sand to obtain very smooth finishes on any type of castings without endangering the quality of the casting through blows or scabs." [10]

[9] Donaldson, Harris M., and others, op. cit., pp. 149-150.
[10] Donaldson, Harris M., and others, op. cit., pp. 148-149.

Table 9. Sieve analysis, Oceano Beach sand.
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 40	.1	.1
50	1.0	1.1
70	9.6	10.7
100	63.8	74.5
140	25.5	100.0
200	.9	100.9
A.F.A. fineness number		77

NATURALLY BONDED SANDS

Alameda County

Livermore "Ganister". A natural mixture of high-silica sand and anauxite clay, known to California foundrymen as "Livermore ganister" was first used in 1942. It is produced by the Tesla Clay and Sand Company of San Francisco, from a deposit in the old Tesla coal-mining district near Corral Hollow and about 9 airline miles east of Livermore.

"Ganister" in strict sense is a term applied to quartzite or other silica rock. This material when crushed and mixed with fire clay is used as a refractory in ladle patching and furnace linings. The Livermore "ganister," a natural material, has actually been misnamed, but has some of the same uses as a true ganister-clay mixture.

The Livermore "ganister" occurs as a unit of the middle Eocene Tesla formation as described and mapped by Huey.[11] The formation has periodically yielded commercial quantities of high-grade fire clay, and previous to 1919 was worked for coal. The economic geology of the area has been discussed by Dietrich.[12] Allen [13] has described the mineralogy of the Tesla sands and clays.

Table 10. Analyses and firing properties of selected Livermore "ganister" samples.
(Analyses furnished by Tesla Clay and Sand Co.)

	Percent sand	Percent clay	Cone of fusion	Temperature of fusion
Sample with maximum sand content	74.7	25.3	30	3,002° F.
Sample with minimum sand content	63.2	36.8	28	2,939° F.
Average sample	68.7	31.3	29+	2,984° F.

The "ganister" of the present operation is a single bed with an average thickness approximating 15 feet. It is white with local light-buff areas, is poorly stratified, and appears uniform in both composition and grain size. According to available analyses, the sand grains fall chiefly

[11] Huey, Arthur S., Geology of the Tesla quadrangle: Bull. California Div. Mines, in preparation, 1947.

[12] Dietrich, W. F., The clay resources and the ceramic industry of California: California Div. Mines Bull. 99, pp. 44-45, 1928.

[13] Allen, V. T., Eocene anauxite clays and sands in the Coast Range of California: Geol. Soc. America Bull., vol. 52, pp. 274-277, 1941.

within the 50- to 200-mesh range, and the clay content averages 31 percent. The bed is clearly exposed in the vicinity of the mine, and the operators report that it can be traced for 6,000 feet to the west and 2,000 feet to the east. The following figures are from analyses and tests of a series of samples "taken from a 2,000-foot outcrop." [14]

At the mine the "ganister" bed is bordered by well-stratified, coarse, buff to gray sandstone containing gray siltstone layers and clay nodules. The section strikes 69° W., dips approximately 60° NE. and is exposed on the steep north slope.

The "ganister" bed is mined vein-like by underground methods. The ore is crushed with a hammer mill on the property, is stored in covered bins, and trucked to consumers or to a rail siding about 9 miles to the west.

> "Livermore 'Ganister' is being widely used in synthetic facings for medium and heavy iron work . . . The sand is fine enough—A.F.A. 99—so that its addition to facing mixtures does not affect the finish, while the fact that the sand is high in silica makes it desirable from the refractory standpoint.
>
> "The clay in the Livermore 'Ganister' is exceedingly refractory . . . Unfortunately, the Livermore 'Ganister' is too high in clay to be used straight as a molding sand . . . (and) it is blended with sharp sands and milled . . . In using Livermore 'Ganister' in place of fire clay in facings, the heaps do not lose permeability as fast because of the quartz sand in the material . . ." [15]

[14] Data furnished by Tesla Clay and Sand Company from an unpublished private report.
[15] Donaldson, Harris M., and others, op. cit. p. 119.

Table 11. Sieve analysis, Livermore "ganister."
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 12	.3	.3
20	.8	1.1
30	1.0	2.1
40	2.9	5.0
50	5.2	10.2
70	15.8	25.0
100	12.2	38.2
140	8.3	46.5
200	4.5	51.0
270	2.1	53.1
Pan	6.0	59.1
Clay	39.4	98.5
A.F.A. fineness number		99

Table 12. Sieve analysis, sand fraction sample, Livermore "ganister."
(Analysis supplied by Tesla Clay and Sand Co.)

Sieve size	Percent retained	Cumulative percent
On 20	.2	.2
30	1.0	1.2
50	16.8	18.0
70	24.2	42.2
100	28.4	70.6
140	24.0	94.6
200	3.5	98.1
—200	1.6	99.7

Table 13. Chemical analysis, sand fraction sample, Livermore "ganister."
(Analysis supplied by Tesla Clay and Sand Co.)

	Percent
SiO_2	97.23
Al_2O_3	1.61
Fe_2O_3	.14
TiO_2	.12
N_2O	.03
K_2O	.20
MgO	Tr.
Ignition loss	.51

In a projected plant the operators hope to wash the clay from the sand and to market the two products separately. The screen and chemical analyses of sand fraction samples in tables 12 and 13 have been supplied by the Tesla Clay and Sand Company.

Los Angeles County

Los Angeles Heavy Molding Sand. The name "Los Angeles Heavy" is applied to molding sand that for more than 50 years has been removed from a group of excavations in the vicinity of Effie Street and Bishops Drive, Los Angeles. The present source is a large pit (pl. 5*B*) at the west termination of Effie Street near the Elysian Park boundary. This pit, operated by Westlake and Sons, has been in nearly continuous production since 1919.

The molding sand occurs as trough-like alluvial fill in a small ravine. At the lower end of the pit the body is 250 feet wide and is reported to have had a maximum thickness of 50 feet. The body wedges out at a point about 500 feet upstream. Bedrock is a light-buff Pliocene sandstone, and the overburden is a 3-foot earthy layer. The principal molding sand body is light brown but it grades upward into darker material. Otherwise it is uniform throughout the present exposures. It is characterized by an absence of stratification and by minute pores.

Table 14. Sieve analysis, Los Angeles Heavy molding sand.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 10	.5	.5
20	2.4	2.9
30	2.8	5.7
40	5.4	11.1
50	7.7	18.8
70	10.6	29.4
100	14.8	44.2
140	13.8	58.0
200	8.5	66.5
270	4.4	70.9
Pan	8.8	78.7
Clay	20.6	99.3

A.F.A. fineness number	102
Green compression strength	15.1 psi
Dry compression strength	53.5 psi
Green shear strength	4.9 psi
Dry shear strength	18.0 psi

Portions of the deposit contain small, sparsely scattered shale fragments. Sandstone cobbles and boulders, though not abundant, are most common near the base of the deposit. The material is removed with a Speerwell machine (pl. 5 *B*) and is loaded on trucks in the same operation. It is riddled before use.

Los Angeles Heavy is comparable in its properties and application to heavy sands produced in the San Francisco Bay area. It is used, therefore, only in southern California foundries and principally in heavy iron castings.

Torrance Lobond Molding Sand. Lobond, a low-clay sand, is produced in the Torrance area by Brumley-Donaldson Company for distribution to foundries of the Los Angeles area. The present source is an excavation northeast of the intersection of Torrance Boulevard and Madrona Avenue (pl. 6*A*). The sand occurs as fine-grained, flat-lying Quaternary alluvium beneath a surface of low relief and covered with a few inches of gray, sandy overburden. The excavation has exposed a 15- to 20-foot thickness through which the sand, except for slight color differences, is very uniform. The lower limit of the deposit is not visible. The sand is predominantly light buff but contains a few grayish layers several inches in thickness. Slight differences in consolidation cause a crude horizontal stratification.

The sand is removed and loaded on trucks with a power shovel and is hauled directly to foundries or to a plant in Los Angeles where it is mixed with clays and other sands in a Simpson mixer, previous to distribution. The uniformity of the deposit and ease of removal permit a steady supply of clean material.

Torrance Lobond has a close grain distribution; 85 percent of the grains will be retained on the 70- to 140-mesh screens. It is a very flexible sand in that it is used for green-sand cores in soil-pipe shops, and as a base sand in the preparation of synthetic or blended molding sands for gray-iron and non-ferrous work.

The analyses (table 15) supplied by the Brumley-Donaldson Company is typical of the Lobond currently produced.

Table 15. Sieve analysis, Torrance Lobond molding sand.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 30	.2	.2
40	.8	1.0
50	2.4	3.4
70	15.2	18.6
100	36.8	55.4
140	33.0	88.4
200	7.2	95.6
270	4.0	99.6
Pan	.2	99.8
Clay	3.2	103.0
A.F.A. fineness number		90

Torrance-Redondo Molding Sands. Several medium to moderately heavy sands are removed from a series of excavations in the Torrance-Redondo area of Los Angeles County. Two sands, ''D-5'' and ''S-4'', are produced by the Harry E. Blood Company; another pair, known as ''77''

Table 16. Sieve analysis, D-5 molding sand.
(Analysis supplied by Harry E. Blood)

Sieve size	Percent retained	Cumulative percent
On 40	.5	.5
50	1.0	1.5
70	22.0	23.5
100	50.8	74.3
140	8.0	82.3
200	1.0	83.3
Pan	1.0	84.3
Clay	15.7	100.0

A.F.A. fineness number	71
Permeability	100
Green compression strength	15.4 psi

Table 17. Sieve analysis, S-4 sand.
(Analysis supplied by Harry E. Blood)

Sieve size	Percent retained	Cumulative percent
On 30	.2	.2
40	.4	.6
50	.6	1.2
70	8.2	9.4
100	48.0	57.4
140	24.2	81.6
200	2.4	84.0
Pan	.8	94.8
Clay	15.0	99.8

A.F.A. fineness number	82

Table 18. Sieve analysis, "77" molding sand
(Analysis supplied by Caswell & Co.)

Sieve size	Percent retained	Cumulative percent
On 30	.1	.1
40	.3	.4
50	.7	1.1
70	3.1	4.2
100	41.8	46.0
140	28.0	74.0
200	5.1	79.1
270	1.6	80.7
Pan	5.3	86.0
Clay	14.0	100.0

A.F.A. fineness number	99
Permeability	80
Green compression strength	16 psi

and "99" are produced by the Caswell Company. All four are processed at a common plant on the property of the Moneta Brick Company of Lawndale (pl. 6*B*).

The Torrance-Redondo area is underlain by flat-lying Quaternary alluvial deposits that are best exposed in the hills separating the cities of Torrance and Redondo Beach. The beds range from deep, reddish buff to light tan in color and may consist of either massive, uniform beds or stratified beds in which individual strata are typically several inches thick and vary in their degree of consolidation. The massive beds reportedly are poorer in clay than the stratified beds, and, where both types are exposed in the same excavation, some control may be exercised on the clay content of the product by selective mining and blending.

Each of the sands is removed by power shovel and trucked to the Lawndale plant where it is mulled and stored previous to removal by truck to the foundries.

D-5 is produced from an excavation east of Redondo and immediately southeast of the junction of the Santa Fe railroad and Redondo Boulevard. Here a reddish-brown, massive sandstone, exposed in a 10- to 20-foot face, grades laterally into lighter brown and better stratified sandstone and siltstone. D-5 is a heavy molding sand which, according to an analysis submitted by Harry E. Blood, has a clay content approximating 16 percent and a concentration of over 70 percent retained on the 70- and 100-mesh screens.

D-5 is used principally in heavy castings and, to a lesser extent, in blends with finer sands.

The S-4 deposit was not visited by the author. According to Mr. Blood, it is a medium-weight sand which contains approximately 15 percent clay and has a concentration of more than 70 percent on the 100- and 140-mesh screens. The sand is reported to have good permeability, strength, and flowability. It is used principally "on bench and medium weight floor molding jobs" and is also "a good soil pipe and soil pipe fitting sand."[16]

[16] Harry E. Blood, written communication.

Table 19. Sieve analysis, "99" molding sand
(Analysis supplied by Caswell & Co.)

Sieve size	Percent retained	Cumulative percent
On 20	.8	.8
30	.7	1.5
40	6.6	8.1
50	20.4	28.5
70	42.2	70.7
100	19.9	90.6
140	1.6	92.2
200	.4	92.6
270	.3	92.9
Pan	1.2	94.1
Clay	6.5	100.6

A.F.A. fineness number	55.5
Permeability	128 to 190
Green compression strength	8.2 to 10.5 psi

It was not practicable for the author to visit deposits of the "77" and "99" sands, but Caswell and Company kindly supplied samples and pertinent data (see tables 18, 19). Both are reported as removed from relatively large excavations in the hills immediately east of Redondo. Both are dark, reddish-brown, heavy sands used in iron casting.

Orange County

Trabuco "Ganister" or "Ganite." Another natural mixture of silica sand and clay, essentially similar to the Livermore "ganister" in composition, occurrence, and use, is obtained from a belt of Eocene sediments on the southwestern flank of the Santa Ana Mountains. Here, too, the term "ganister" is a misnomer, but is generally used by southern California foundrymen. In fact, this term as applied to the natural mixture seems to have been first used in reference to the Trabuco material.

Trabuco "ganister" or "Ganite" is, at present, produced from at least two properties in the vicinity of the Robinson ranch 1.5 miles from Trabuco Oaks on the Trabuco Canyon Road. A series of excavations operated by I. P. Arnold mainly as sources of china clay are just east of the ranch buildings. The H. J. and Hester R. Borchers deposit joins the Arnold operation on the south. "Ganister" material is reported to have also been marketed from the "Beardslee deposit," north of Trabuco Canyon.

Table 20. Sieve analysis, "ganister" from Borchers deposit.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 16	2.7	2.7
20	11.6	14.3
30	9.0	23.3
40	9.0	32.3
50	7.4	39.7
70	5.5	45.2
100	4.2	49.4
140	4.7	55.1
200	3.7	58.8
270	1.5	60.3
Pan	4.3	64.6
Clay	35.6	100.2
A.F.A. fineness number		32

Table 21. Sieve analysis, sand separate from Arnold plant.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 16	11.9	11.9
20	20.4	32.3
30	21.4	53.7
40	23.0	76.7
50	12.8	89.5
70	6.8	96.3
100	2.2	98.5
140	.6	99.1
Pan	.4	99.5
A.F.A. fineness number		26.6

Near the Robinson ranch the workings are confined, in general, to a 40-foot thickness of the Eocene section. The sediments are poorly consolidated and crudely stratified and are locally crossbedded. They range from quartzitic conglomerate to clay-rich sandstone containing "kidneys" of sand-free clay. The mineral percentages and grain-size distribution, therefore, are not as uniform as those of the Livermore "ganister." Large lenticular bodies parallel with the stratification are, however, of uniform composition and are being selectively mined from the open-cut faces. The "ganister" is actually the unwashed clay-bearing material.

The Trabuco "ganister" on the Arnold property is blasted from the excavation walls, is mechanically loaded on trucks, and is hauled a short distance to a processing plant. Here it is screened to remove the quartzitic pebbles and cobbles and crushed. It is then trucked for distribution in the Los Angeles area. A similar procedure is followed at the Borcher's deposit.

Like the Livermore "ganister" the Trabuco product is used as a refractory material in ladle patches and furnace lining. It has had but a limited use as a clay-rich base for synthetically prepared molding sand. The coarseness of the silica may hinder its acceptance in this field. Otherwise its properties should be similar to those of the Livermore "ganister."

Santa Ana Molding Sands. A group of molding sands with a wide range of properties and uses is produced by V. J. Frye of Santa Ana from the vicinity of the Irvine ranch about 4 miles southeast of Tustin. The author found an inspection of these deposits impracticable, but the sands are presumably obtained from the Miocene marine sediments that are exposed in the area or possibly, in part, from the Pliocene (?) and Quaternary deposits that lie along the western flank of the older rocks.

The sand products as distributed by the Brumley-Donaldson Company have acquired a variety of names. Two light molding sands are respectively known in the Los Angeles area as "Donco Light" (or "Santa Ana Light") and "Delarama." In the San Francisco Bay area the names "Del Mar" or "Santa Ana" are applied to either of the Santa Ana light sands. A coarser sand known as "Donco Heavy," "Santa Ana Heavy," or "F-6" has so far been distributed almost entirely to southern California foundries. "F-7" refers to a Santa Ana sand with a low bond. "Donco Medium" is a medium-weight sand. The name "Fargo" is applied to a blend of heavy and light sands.

The sand is removed by power shovel and trucked to a plant in Santa Ana (pl. 7*A*). Here it is passed through a $\frac{3}{4}$-inch-mesh rotary screen to remove the pebbles and cobbles of harder rocks that are sparsely scattered through most of the material. It is then carried through rollers that crush the larger lumps, and is finally conveyed to storage sheds in which limited winter reserves are accumulated. The operator is reported to take considerable care to prevent contamination and assure uniformity.

Donco Light is a light-yellow sand very similar in appearance and adaptability to San Diego sand. Like San Diego sand it is unusually fine grained and may contain appreciable amounts of calcareous matter. It is well suited for light castings such as stove plate, regular red and yellow brasses and aluminum, and is reported to impart a satin-smooth finish to castings of these metals.

Delarama, according to analyses furnished by Brumley-Donaldson Company (table 23) has a slightly coarser base and a considerably higher

Table 22. Sieve analysis, Donco Light molding sand.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 70	2.9	2.9
100	1.1	4.0
140	1.9	5.9
200	13.5	19.4
270	17.7	37.1
Pan	45.0	82.1
Clay	19.0	101.1

A.F.A. fineness number	222
Permeability	13.5
Green compression strength	10.3 psi
Dry compression strength	26.3 psi

Table 23. Sieve analysis, Delarama sand.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 20	1.0	1.0
30	1.3	2.3
40	1.2	3.5
50	1.2	4.7
100	1.6	6.3
140	5.5	11.8
200	18.2	30.0
270	11.7	41.7
Pan	30.5	72.2
Clay	28.0	100.2

A.F.A. fineness number	204.5
Green compression strength	12.5 psi
Dry compression strength	24.5 psi

Table 24. Sieve analysis, Donco Heavy sand.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 20	.4	.4
30	.9	1.3
40	3.9	5.2
50	10.3	15.5
70	20.8	36.3
100	25.0	61.3
140	15.2	76.5
200	2.4	78.9
270	2.1	81.0
Pan	3.0	84.0
Clay	16.0	100.0

A.F.A. fineness number	78.0

clay content than Donco Light. This sand is widely used in light iron shops and is particularly popular for casting soil pipe and fittings. It is claimed to handle easily and to have good durability.

Donco Heavy is a reddish sand with a wide grain-size distribution that has its greatest concentration on the 40- and 50-mesh screens. The deposit is reported to be extensive and consistently uniform. Its rather high clay content of approximately 20 percent is considered desirable. The sand is used principally in heavy iron castings with some slight use in heavy brass work.

Table 25. Sieve analysis, Donco Medium sand.
(Analysis supplied by Brumley-Donaldson Co.)

Sieve size	Percent retained	Cumulative percent
On 16	.1	.1
20	.1	.2
30	.1	.3
40	.4	.7
50	1.3	2.1
70	4.2	6.3
100	8.4	14.7
140	13.9	28.6
200	22.2	50.8
270	10.9	61.8
Pan	19.5	81.3
Clay	18.9	100.2

A.F.A. fineness number	168
Permeability	18.0
Green compression strength	14.0 psi
Dry compression strength	82.5 psi

Riverside County

Riverside Molding Sand. Riverside molding sand, also known as "V3" or "Pedley sand," has been mined intermittently west of Riverside in the vicinity of the Santa Ana River channel. An excavation on the north bank, formerly operated by Westlake and Sons of Los Angeles is now idle. The Jurupa deposit (pl. 7*B*), an excavation south of the river, has been opened in recent years by Miller Brothers of Huntington Park. This is the only current source.

The sand occurs as a reddish layer on the surface of a Quaternary terrace. At the Jurupa deposit this layer is from 6 to 8 feet thick and is underlain in part by light-gray silty sediments. A granite rock is reported to occur beneath a portion of the excavation. The overburden consists of clay-poor sand that averages 1 foot in thickness.

The molding-sand layer is unstratified, poorly consolidated, and contains many minute sponge-like pores. Small igneous pebbles are sparsely scattered throughout the layer. Within the limits of the excavation, the sand is both vertically and laterally uniform. A similar material occurs as a thin, residual mantle on nearby granitic hills that project above the terrace surface. The layer in the excavation apparently is also a weathering product of the granite rock and has been transported but a short distance.

The sand is mined by a bulldozer and is loaded on trucks from a ramp. At the operators' Huntington Park plant it is either mulled or treated with a roll-type pulverizer and stored in bins for distribution.

Riverside sand, according to the operators, has been found most suitable for light gray iron, brass, and bronze castings. A smooth finish is produced.

Table 26. Sieve analysis, Riverside molding sand.
(Analysis by H. Ries)

Sieve size	Percent retained	Cumulative percent
On 20	.6	.6
40	1.4	2.0
50	1.0	3.0
70	1.4	4.4
100	2.7	7.1
140	5.0	12.1
200	12.4	24.5
270	9.0	33.5
Pan	44.8	78.3
Clay	21.7	100.0

A.F.A. fineness number	*222
Permeability	10.0
Green compression strength	*8.0 psi

* Figures supplied by Miller Brothers Trucking Company.

Sacramento County

Sacramento Red Molding Sand. A heavy molding sand which at present is distributed only to foundries in the Sacramento area is produced by Cannon and Company of North Sacramento. The sand occurs as the top layer of the Quaternary alluvium underlying the area of the company's plant. It is removed by bulldozer in the winter months and is hauled by truck directly to the foundries.

Most of the Sacramento Red production is consumed in the local Southern Pacific foundries where it is used chiefly in casting gray iron car wheels and engine parts. Screen analyses were not available to the author. Data supplied by P. V. Garin, Southern Pacific Company, indicates green, dry and base permeabilities of 23, 34 and 9 respectively.

San Diego County

San Diego Molding Sand. San Diego molding sand has been produced for many years from the extensive Pliocene deposits underlying the city of San Diego. Building excavations supplied much of the early material, but larger, sustained operations in later years have produced a more uniform product. The only current source is an excavation opposite the 2700 block of Arroyo Drive, a property owned and operated by H. M. Hubbard of Los Angeles.

The present face is approximately 500 feet long and as much as 65 feet high (pl. 8*A*). The entire face, with the exception of minor limy concretionary or fossiliferous layers and a gray, sandy overburden of 4 feet or less, is mined as molding sand. The sand is yellowish buff and is locally mottled light gray to deep buff. Its crude stratification is essentially horizontal. Portions of the section contain abundant shell fragments, but most of the material is free from megascopic calcareous bodies.

The face is cut back with a power shovel, and the freshly excavated sand is worked with a hand shovel to remove the concretions. The sand containing shell fragments is moved separately and is run by hand shovel through a ¾-inch screen. Trucks carry the sand to the shipping point.

Table 27. Sieve analysis, San Diego molding sand.
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 12	.3	.3
20	.4	.7
30	.4	1.1
40	.5	1.6
50	.6	2.2
70	.6	2.8
100	.8	3.6
140	1.5	5.1
200	8.2	13.3
270	19.2	33.5
Pan	50.2	84.7
Clay	19	103.7
A.F.A. fineness number		234

San Diego sand has one of the finest grain sizes of the California molding sands, 65 percent of the grains passing through the 270-mesh screen. Like most of the light California molding sands, it carries a small quantity of lime.

> "This sand is most commonly used in light iron or stove plate work, in regular red and yellow brasses, and for aluminum. It is more suitable for aluminum than the other metals because it is so exceedingly fine. . . Aluminum . . . is not a gassy metal, and it is therefore possible to employ extremely fine sands for molding, for, by so doing, excellent finishes can be obtained. . . This is not the case, however, when working in brass or bronze. San Diego sand can be handled with extreme care in the production of these metals in order to produce good castings.
>
> "Its durability properties are in direct proportion to the clay content percentage . . . and the clay is not particularly refractory. The new sand permeability is 8."[17]

San Francisco County

San Francisco Mission Red Molding Sand. Mission Red is a heavy molding sand with a long-established acceptance in foundries of the San Francisco Bay area. It is produced by the Gallagher Foundry Supply Company of San Francisco and is obtained chiefly from building excavations within the city limits. It occurs as a reddish-brown Quaternary alluvial capping that underlies the thickly settled Mission district and now has few surface exposures. Apparently it is physically and geologically similar to the beds from which San Francisco 440 molding sand is obtained near the city of South San Francisco, and the reader is referred to a description of this deposit in the following section.

A divergence in grain size and clay content of sands from the numerous Mission Red sources is inherent in its production method. Its producers, however, attempt to maintain a uniform product by selective removal and blending.

[17] Donaldson, Harris M., and others, op. cit. pp. 123-124.

The sand is generally removed by power shovel and trucked to the Gallagher plant where it is stock-piled, fed through a hammer mill, and stored in a covered shed. It is used in heavy iron and brass casting.

Mission Red has a clay content of approximately 17 percent, a property which "assures ample green or dry strength for heavy iron or brass work. It is also blended with sharp sands, such as Del Monte regular or Lapis No. 2, where higher permeability is required."[18]

Table 28. Sieve analysis, San Francisco Mission Red molding sand.
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 12	.1	.1
20	.4	.5
30	3.2	3.8
40	7.1	10.9
50	14.2	25.1
70	23.9	49.0
100	19.9	68.9
140	5.5	74.4
200	2.4	76.8
270	1.0	77.8
Pan	4.4	82.2
Clay	17.0	99.2
A.F.A. fineness number		69

San Mateo County

Millbrae Blended Molding Sand. "Millbrae" is a light molding sand produced by Brumley-Donaldson Company from the hills west of Millbrae. Though introduced relatively recently, it is being widely used in foundries of the San Francisco Bay area. Extensive deposits of the base material were uncovered in the large excavations supplying fill for the San Francisco airport.

The molding sand occurs as yellowish, poorly stratified material that appears to be an oxidized portion of the gray marine siltstone that underlies it. These beds, part of the Merced Pliocene formation,[19] are moderately deformed. The yellow sandstone is softer than the gray underlying rocks. The contact between the two is sharp and irregular in detail, but is, in general, parallel with the topographic surface. Shell-rich layers and the more pronounced beds of the gray siltstone transect the contact. The layer, as now exposed in the higher parts of the ridge, ranges up to 20 feet in thickness and is covered with a 1- to 2-foot over-burden of soil. It is stated to be similar to the Santa Barbara sand and to have a new sand permeability of about 12.

The molding sand produced in this area is, of course, an insignificant fraction of the sand removed for fill. The Brumley-Donaldson Company, however, hope to continue to supply a Millbrae sand after the larger operation has ended. The sand is mined by power shovel and trucked to the South San Francisco plant where it is fed through a hammer mill and a $\frac{1}{8}$-inch-mesh screen. It is then blended with bentonite or fire clay to meet individual foundry specifications.

[18] Donaldson, Harris M., and others, op. cit. p. 116.
[19] Lawson, A. C., U. S. Geol. Survey, Geol. Atlas, San Francisco folio (no. 193), pp. 13-14, 1914.

"(Millbrae blended) . . . has been found suitable for molding stove plates, light iron, and most non-ferrous metals except magnesium. . . (It) has fair refractory values which are increased by the addition of clay during processing. . . It is a smooth working sand which gives a smooth finish to light work . . . but its properties of strength and durability can be substantially increased by mulling."[20]

Table 29. Sieve analysis, Millbrae sand.
(Analysis by D. L. Mason)

Seive size	Percent retained	Cumulative percent
On 6	.8	.8
12	2.5	3.3
20	2.2	5.5
30	.9	6.4
40	.3	6.7
50	.6	7.3
70	.8	8.1
100	2.4	10.5
140	16.4	26.9
200	31.1	58.0
270	7.7	65.7
Pan	24.0	89.7
Clay	12.5	102.2
A.F.A. fineness number		155

San Francisco 440 Molding Sand. "San Francisco 440," a heavy molding sand, is obtained from excavations in the low hills between the city of South San Francisco and the San Francisco Bay shore and has been used in northern California since the early days of the foundry industry. In recent years it has been produced by the San Francisco office of Brumley-Donaldson Company.

The source of San Francisco 440 is a Quaternary alluvial deposit on a weathered surface of Franciscan rocks. This capping ranges in thickness to more than 20 feet. The sand is a light yellowish to reddish buff and is crudely stratified. It has, in general, a uniform grain size and composition, though some of the material appears slightly coarser. Small, rounded igneous and metamorphic pebbles are sparsely scattered throughout all of the exposures.

San Francisco 440 formerly was mined from a prominent hill immediately east and northeast of the present site of the Bethlehem steel plant. Much of the hill and almost all of its sand capping, however, have been removed for fill, and the sand is now obtained from a nearby excavation on Grand Avenue, northeast of the Swift and Company plant (pl. 8*B*). Here a sand face from 15 to 20 feet high is exposed, and bedrock has not been encountered. The deposit is overlain by an earthy overburden 1 to 2 feet thick. In a cut immediately to the east, the sand overlaps an irregular Franciscan surface and has a crude horizontal stratification.

The sand is removed by power shovel in the rainless months and is trucked a short distance to a processing plant. Here it is dried by spreading and working with a bulldozer. It is then fed through a hammer mill and a $\frac{1}{8}$-inch-mesh screen and is stored in a shed sufficiently large for a winter's reserve.

[20] Donaldson, Harris M., and others, op. cit., p. 121.

Table 30. Sieve analysis, San Francisco 440 molding sand.
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 6	.6	.6
12	1.1	1.7
20	.8	2.5
30	.4	2.9
40	.7	3.6
50	4.3	7.9
70	15.6	23.5
100	29.7	53.2
140	11.1	64.3
200	3.1	67.4
270	1.7	69.1
Pan	7.9	77.0
Clay	22.0	99.0
A.F.A. fineness number		95

Table 31. Sieve analysis, Santa Barbara molding sand.
(Analysis by H. Ries)

Sieve size	Percent retained	Cumulative percent
On 20	.4	.4
30	1.1	1.5
50	1.2	2.7
70	1.9	4.6
100	2.8	7.4
140	8.0	15.4
200	31.0	46.4
270	11.2	57.6
Pan	29.6	87.2
Clay	12.2	99.4
A.F.A. fineness number		191

Table 32. Sieve analysis, Lompoc molding sand.
(Analysis by D. L. Mason)

Sieve size	Percent retained	Cumulative percent
On 12	.2	.2
20	.1	.3
30	.6	.9
40	4.5	5.4
50	20.8	26.2
70	33.4	59.6
100	22.2	81.8
140	7.8	89.6
200	2.4	92.0
270	1.0	93.0
Pan	1.4	94.4
Clay	9.3	103.7
A.F.A. fineness number		63

San Francisco 440, like Mission Red, is used principally in heavy iron and heavy brass casting. These sands are, therefore, comparable to Los Angeles Heavy and are not distributed in the southern California area.

> "The actual permeability (of San Francisco 440) is around 50, which is fairly high, considering the high clay content. This clay content, approximately 22 percent, can be put to good advantage by using this sand as a blend with sharp sands. The permeability of the blended sands can be increased to as high as 150 by proper selection of the blend and by proper preparation—mulling and aeration.
>
> "Good durability qualities and good finish on the castings can also be obtained by the addition of sea coal and pitch to the facing mixes." [21]

Santa Barbara County

Santa Barbara Molding Sand. A light molding sand known as "Santa Barbara" or "V-2" met with wide use in southern California foundries during World War II. It was produced by Miller Brothers of Huntington Park from the Scavarda ranch near Goleta. The excavation itself is on a hillside immediately west of the western property line of the Santa Barbara County Hospital (pl. 9*A*).

The sand occurs as a single, poorly consolidated bed in a section of Pliocene marine sediments. The exposed bed ranges from 20 to 25 feet in thickness; it strikes approximately N. 60° E. and dips 40° SW. It is bordered on top and bottom by limy fossiliferous sandstones that are reported to have a lower clay content and to be unsuited for foundry use. The molding sand is uniformly yellow and even grained and is said to resemble one of the famous Albany molding sands in appearance and workability.

The sand was removed selectively by power shovel and trucked to a processing plant in Huntington Park, where it was pulverized or mulled and stored in bins. The operation was suspended when the excavation face approached the hospital property line near a reservoir. An absence of exposures in the vicinity has hindered the search for a new source, and there is little prospect for further production from the present excavation. It is likely, however, that systematic exploration would uncover similar material in the area.

> "This sand is particularly good for light iron, brass, bronze, or aluminum. Having a clay content of 11.4%, some rebonding with bentonite or fire clays must be done to increase its durability. No base permeability figures are available, but the grain distribution shows this sand is coarser and more open than San Diego sand . . . It works nicely at moisture ranges of from 5 to 7 percent and flows well around the pattern." [22]

Lompoc Molding Sand. "Lompoc" molding sand was introduced shortly before World War II, and for several years was widely used in foundries of both northern and southern California. Recently, however, the deposit has been worked only intermittently. The sand is obtained from the V. C. Campbell ranch on State Highway 150, midway between Lompoc and Buellton. The deposit is leased and operated by Miller Brothers of Huntington Park.

The sand occurs in a section of horizontal, ridge-forming Pleistocene marine sediments[23] that locally project above Recent deposits of a

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[21] Donaldson, Harris M., and others, op. cit., p. 115.

[22] Donaldson, Harris M., and others, op. cit., pp. 121, 122.

[23] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, California: U. S. Geol. Survey Bull. 322, pp. 61-62, 1907.

tributary of the Santa Ynez River. The original excavation is at the southwestern termination of a low ridge near the Pleistocene-Recent contact. A 15-foot section is exposed in the irregular excavation face, but only the lower 5 feet is reported as desirable molding sand. This portion consists of sandstone of uniform grain size and mineral composition. Local light-buff, slightly concretionary layers are the result of iron oxide concentrations. The molding sand is overlain by light-tan, poorly cemented sandstone that has been found deficient in clay and unsuited for foundry use. The tan material is, therefore, an overburden that increases in thickness ridgeward from the excavation face. The molding sand has been removed to a depth of 8 feet beneath the present excavation floor. Continued production of the sand at this locality, however, will become increasingly difficult. A second excavation about an eighth of a mile to the northeast and 30 feet higher on the ridge has exposed another 15-foot section of sandstone. This, though similar in appearance to the molding sand of the lower excavation, is reported to have a lower clay content. It has been marketed, but its future availability to industry is uncertain at the time of this writing.

> "(Lompoc sand) has the desirable characteristics of higher permeability and a very good clay percentage balance which make it highly workable in heavy iron and brass. . .
>
> "This sand is one of the most refractory natural sands produced in California. The base sand has a high percentage of silica—approximately 90 percent—and the clay also has good refractory values.
>
> "The base permeability of the sand probably will run over 100, although actual figures are not available at this time. The grain distribution is very good with 84.2% laying between the 40 and 140 mesh screens . . .
>
> "While the clay has better refractory values, in comparison with other California molding sands, the percentage of clay is not high enough to provide excellent durability characteristics. Therefore, after repeated usage, it is necessary to rebond with bentonites or fire clays to maintain sufficient strength.
>
> "When worked new in facings, with sea coal and pitch added, the high permeability and good strength characteristics provide sound castings and good finish, with moisture ranges of 5 to 7%. This sand can be rammed hard without danger of blows or scabs."[24]

A sample of Lompoc sand tested by Ries showed only slight vitrification at 2500° fahrenheit.

Ventura County

Ventura Molding Sand. "Ventura" or "V-2" molding sand has been widely used by southern California foundries for nearly 30 years. Its source, an excavation within the city limits (pl. 9*B*), is reached by a short road north and west from the 200 block, Aliso Street. The property is owned and was formerly operated by Charles A. Cole of Ventura. The present operator is the Ventura Molding Sand Company, O. D. Messmore, President.

The sand occurs as a bed about 100 feet thick in a section of Pleistocene[25] marine sediments. The bed strikes approximately N. 85° E. and dips 47° S. Bordering sandstones are clay-poor and unsuited for foundry purposes. The molding sand is light tan and unconsolidated, and there is little apparent variation in grain size or mineral composition throughout the exposure. Portions of the bed, however, contain scattered shell fragments, and the sand itself is slightly calcareous.

[24] Donaldson, Harris M., and others, op. cit., p. 117.
[25] Unpublished geologic map, Stanford Geological Survey, 1929.

Table 33. Sieve analysis, Ventura molding sand.
(Analysis by H. Ries)

Sieve size	Percent retained	Cumulative percent
On 20	.4	.4
40	.2	.6
50	.1	.7
70	.2	.9
100	.3	1.2
140	1.6	2.8
200	18.8	21.6
270	15.8	37.4
Pan	42.2	79.6
Clay	20.4	100.0
A.F.A. fineness number		234

The cut, when visited, was approximately 120 feet long, 80 feet high and 175 feet in from the hill slope. The material is removed by power shovel and run through rotary-type screens, the first a $\frac{1}{4}$- by $\frac{7}{8}$-inch mesh, the second a $\frac{1}{8}$-inch mesh. It is then bulldozed to a loading chute and is distributed by truck.

Ventura sand is best suited to gray iron, aluminum, and brass castings. It is similar to San Diego sand, in origin, grain-size distribution, and mineral composition. Its extreme fineness of grain produces a good finish but provides a relatively low permeability.

MISCELLANEOUS DATA AND OBSERVATIONS

Sand from one undeveloped area is now being tested as foundry material and may soon become available. This sand, to be known as "Callender 70," is a dune-type sand exposed over an area of 6 square miles immediately east of Callender station on the Southern Pacific Railroad and about 4½ airline miles south of Oceano. A. E. Gordon, who controls the property, submits the following screen analysis (table 34) as representative.

Table 34. Sieve analysis, Callender 70 sand.
(Analysis supplied by A. E. Gordon)

Sieve size	Percent retained	Cumulative percent
On 30	Tr.	----------
40	.2	----------
50	5.0	----------
70	24.2	----------
100	50.2	----------
140	20.2	----------
—140	.2	----------
A.F.A. fineness number		72
Base permeability		120

Table 35. Screen analyses of some clay-free California foundry sands.

Location of deposit	Name of sand	Percent retained on sieves										A.F.A. fineness number
		12	20	30	40	50	70	100	140	200	—200	
Contra Costa County												
Antioch	Antioch-Marchio medium[1]	----	0.4	----	25.8	19.1	16.2	17.5	11.0	4.0	[2]5.2	63
	Antioch-Marchio fine[1]	----	0.8	----	6.0	6.4	17.2	35.4	23.0	6.0	[3]4.5	78
Pittsburg	Pittsburg-Roberts	----	2.3	8.8	15.0	22.8	25.2	18.6	4.5	1.0	0.7	49
Monterey County												
Del Monte	Del Monte[4]	----	1.0	8.0	38.0	35.0	16.0	2.0	----	----	----	37
	Minus 60[4]	----	----	----	5.0	55.0	35.0	5.0	----	----	----	45
Lapis	Lapis No. 2[5]	----	0.7	5.6	20.0	41.8	27.0	4.6	0.2	----	----	41
	Dried Lapis No. 2[6]	----	----	2.0	8.0	50.0	25.0	10.0	4.0	1.0	----	48
San Francisco County												
San Francisco	San Francisco Dune[5]	----	0.1	0.1	1.4	8.6	35.8	40.1	12.4	1.2	----	64
San Luis Obispo County												
Oceano Beach	Oceano[5]	----	----	----	0.1	1.0	9.6	63.8	25.5	0.9	----	77

[1] Analysis by Heinrich Ries.
[2] Includes 0.8 percent 270 mesh, 2.4 percent pan and 2.0 percent clay.
[3] Includes 0.6 percent 270 mesh, 1.9 percent pan and 2.0 percent clay.
[4] Analysis by E. W. Galliher.
[5] Analysis by D. L. Mason.
[6] Analysis submitted by Pacific Coast Aggregates Inc.

Although most California foundry sands are purchased as unblended natural materials, there is a present trend among the larger distributors to supply "custom-made" sands for specific jobs. A "Donco Special" sand as distributed by Brumley-Donaldson Company, for instance, may consist of any materials at the producer's disposal and would be designed to produce particular physical properties not obtainable in a single natural sand.

It will be apparent to the reader that the foundry sand industry is not altogether stable, but is influenced by a number of variables. Among these are technological advances, both in foundry practice and sand production and control. The unnaturally increased production demands brought about by World War II induced the introduction of new sands, many of which are still widely used. Under these conditions too, large-tonnage operations producing what are essentially aggregate sands may also contribute materials to foundries. In normal times, however, these producers find foundries an almost insignificant market. As an example, the Crystal Silica Company deposit in the Eocene sands near Oceanside contributed appreciable amounts of good quality foundry sand during World War II, but its present output for this use is negligible.

Most of the naturally bonded sand sources are in or near densely populated areas, and city and county excavation restrictions present a problem of major concern to many operators. This problem applies both to the continuation of currently operated deposits and to the development of known deposits of desirable material. The recognition and protection of foundry sand occurrences through city and county zoning would materially assist not only the producers but western industry as a whole.

DATA ON NORTHERN CALIFORNIA SAND DEPOSITS, FROM AN UNPUBLISHED REPORT BY E. WAYNE GALLIHER

One of the most comprehensive field studies of northern California sand deposits yet undertaken was completed in 1932 by E. Wayne Galliher. Unfortunately Mr. Galliher's untimely death has prevented publication of his collected data, much of which remains in the form of unavailable field notes. One unpublished report by Mr. Galliher entitled *Northern California Sand Deposits* and originally compiled for a private company has, however, been released to the California State Division of Mines. The material herein contained is abstracted from this report, which, though submitted in 1932, is currently pertinent and emphasizes the need for further study of sand deposits of potential economic value.

Galliher's studies were confined to three principal geologic types of sand sources: (1) coastal sand deposits on or near present beaches; (2) exposures of Santa Margarita (Miocene) sandstones; and (3) Eocene sandstones. Localities of possible potential value were sampled and briefly described. All of the screen analyses are tabulated elsewhere in the present report.

The beach and dune areas studied are at Point Reyes, Fort Bragg, Mendocino, Point Arena, Pudding Creek, Del Monte, Half Moon Bay, Milagra Valley, Pescadero Creek, Point Año Nuevo, and Bodega Head. Of the 11, only one, that at Del Monte (Moss Beach), contains sand relatively free of dark mineral grains and heterogeneous rock particles. The others range in color from light to dark brown; sands at Eureka and Fort Bragg are almost black. Bodega Head sand, considered by Galliher

Table 36. Screen analyses of some naturally bonded California foundry sands

Location of deposit	Name of sand	Percent retained on sieves										Percent		A.F.A. fineness number
		12	20	30	40	50	70	100	140	200	270	Pan	Clay	
Alameda County														
Tesla	Livermore-Ganister [1]	0.3	0.8	1.0	2.9	5.2	14.8	12.2	8.3	4.5	2.1	6.0	39.4	99
Los Angeles County														
Los Angeles	Los Angeles-Heavy[2]	0.5	2.4	2.8	5.4	7.7	10.6	14.8	13.8	8.5	4.4	8.8	20.6	102
Torrance	Lobond[2]	--------	--------	0.2	0.8	2.4	15.2	36.8	33.0	7.2	4.0	0.2	3.2	90
Torrance-Redondo	77[3]	--------	--------	0.1	0.3	0.7	3.1	41.8	28.0	5.1	1.6	5.3	14.0	99
Torrance-Redondo	99[3]	--------	0.8	0.7	6.6	20.4	42.2	19.9	1.6	0.4	0.3	1.2	6.5	56
Torrance-Redondo	D-5[4]	--------	--------	--------	0.5	1.0	22.0	50.8	8.0	1.0	--------	1.0	15.7	71
Torrance-Redondo	S 4[4]	--------	--------	0.2	0.4	0.6	8.2	48.0	24.2	2.4	--------	0.8	15.0	82
Orange County														
Trabuco Canyon	Trabuco ganister or "Ganite"[2]	2.3	12.0	9.0	9.0	7.4	5.5	4.2	4.7	3.7	1.5	4.3	35.6	32
Santa Ana	Delarama[2]	--------	1.0	1.3	1.2	1.2	--------	1.6	5.5	18.2	11.7	30.5	28.0	205
Santa Ana	Donco Light[2]	--------	--------	--------	--------	--------	2.9	1.1	1.9	13.5	17.7	45.0	19.0	222
Santa Ana	Donco Heavy[2]	--------	0.4	0.9	3.9	10.3	20.8	25.0	15.2	2.4	2.1	3.0	16.0	78
Santa Ana	Donco Medium	0.1	0.1	0.1	0.4	1.3	4.2	8.4	13.9	22.2	10.9	19.5	18.9	168
Riverside County														
Riverside	Riverside V-3 or Pedley[5]	--------	0.6	--------	1.4	1.0	1.4	2.7	5.0	12.4	9.0	44.8	21.7	222
Sacramento County														
Sacramento	Sacramento Red	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
San Diego County														
San Diego	San Diego [1]	0.3	0.4	0.4	0.5	0.6	0.6	0.8	1.5	8.2	19.2	50.2	19.0	234
San Francisco County														
San Francisco	Mission Red [1]	0.1	0.4	3.2	7.1	14.2	23.9	19.9	5.5	2.4	1.0	4.4	17.0	69

San Mateo County													
Millbrae	Millbrae Blended [1]	3.2	2.2	0.9	0.3	0.6	0.8	2.4	16.4	31.1	7.7	24.0	12.5	155
South San Francisco	440 [1]	2.5	0.8	0.4	0.7	4.3	15.6	29.7	11.1	3.1	1.7	7.9	22.0	95
Santa Barbara County														
Goleta	Santa Barbara [1]	0.2	0.3	0.3	0.6	0.8	1.3	1.8	7.4	32.0	18.4	25.1	11.5	190
	or V-1 [5]	-------	0.4	1.1	-------	1.2	1.9	2.8	8.0	31.0	11.2	29.6	12.2	191
Lompoc	Lompoc or V-4 [5]	0.2	0.1	0.6	4.5	20.8	33.4	22.2	7.8	2.4	1.0	1.4	9.3	63
Ventura County														
Ventura	Ventura or V-2 [5]	-------	0.4	-------	0.2	0.1	0.2	0.3	1.6	18.8	15.8	42.2	20.4	234

[1] Analysis by D. L. Mason.
[2] Analysis supplied by Brumley Donaldson and Co.
[3] Analysis supplied by Caswell and Co.
[4] Analysis supplied by Harry E. Blood.
[5] Analysis by Heinrich Ries.

Table 37. Screen analyses of some high-silica Eocene sands of central-western California.
(Analyses by E. Wayne Galliher)

Location	Sample	Percent retained on sieves										A.F.A. grain fineness number
		12	20	30	40	50	70	100	140	200	—200	
Contra Costa County												
Nortonville	I crude	-------	-------	1.1	10.1	38.6	25.9	9.8	4.6	2.7	7.2	61
	I washed	-------	-------	1.3	10.9	40.8	30.3	11.7	3.9	0.7	0.2	47
	II crude	0.2	1.9	17.4	30.4	16.5	11.1	7.5	4.5	3.1	7.3	55
	II washed	-------	2.5	23.6	33.9	19.5	11.6	7.2	2.9	0.7	-------	38
Somersville	I crude	-------	1.1	9.0	19.3	25.8	23.8	9.8	4.1	2.1	4.8	53
	I washed	-------	1.0	8.9	22.2	27.2	27.2	9.5	2.9	0.6	0.3	44
	II crude	-------	0.2	1.6	5.0	20.4	38.6	19.4	6.4	3.0	5.5	55
	II washed	-------	-------	1.6	3.0	18.7	44.0	23.8	6.7	2.2	-------	57
	III crude	-------	-------	1.2	3.1	15.3	33.0	27.2	9.8	3.8	6.6	71
	III washed	-------	-------	0.7	4.0	18.0	34.4	28.8	10.6	2.5	1.0	62
Fresno County												
Cantua Creek	Crude	0.2	7.0	6.7	11.8	21.4	19.2	10.8	8.1	5.0	9.8	66
	Washed	0.6	4.6	8.3	10.4	26.4	23.7	12.6	7.9	4.0	1.4	53

Table 38. Screen analyses of sands from the Monterey formation of central-western California
(Analyses by E. Wayne Galliher)

Location	Sample	Percent retained on sieves 12	20	30	40	50	70	100	140	200	—200	A.F.A. grain fineness number
Monterey County												
Big Sandy Creek	Crude	1.6	1.7	4.6	16.1	25.5	18.1	10.0	6.0	4.0	12.6	69.0
	Washed	1.7	1.1	4.5	20.0	30.0	21.2	11.3	6.3	2.5	1.3	32.8
Calera Canyon	I crude				1.6	3.1	6.2	50.0	30.6	4.5	4.0	85.0
	I washed				1.1	0.8	3.1	55.1	33.9	4.9	1.0	82.0
	II crude			4.8	11.3	10.8	20.2	34.8	12.1	2.4	3.3	65.0
	II washed		0.3	4.5	10.9	10.0	18.4	36.4	15.9	2.7	0.9	64.0
	III crude	3.9	32.5	23.6	10.5	6.9	9.5	8.6	2.1	0.7	1.6	32.0
	III washed	3.2	26.6	22.9	11.8	7.5	11.2	11.8	3.6	0.9	0.4	34.0
	IV crude	0.5	4.0	1.3	0.8	6.0	20.2	43.3	17.5	3.4	2.5	71.0
	IV washed	0.6	5.3	1.5	1.0	2.8	18.0	45.8	19.0	4.4	1.6	64.0
	V crude			0.5	2.0	8.6	26.6	30.8	22.6	5.2	3.6	76.0
	V washed				2.3	8.0	23.3	34.8	24.9	5.6	1.1	75.0
	VI crude		1.0	2.4	6.6	18.9	16.4	8.3	29.3	12.0	4.9	85.0
	VI washed		0.9	2.5	7.5	21.1	18.7	7.5	27.9	11.5	2.4	75.0
San Luis Obispo County												
Carpenter Canyon Grade	Crude					6.5	41.3	34.0	9.6	3.3	5.3	71.9
	Washed				0.4	2.3	41.3	39.8	12.6	3.0	0.9	68.2
Reeds	Crude			1.0	1.4	6.3	22.4	37.3	12.6	5.9	12.0	85.3
	Washed				3.5	6.6	30.1	40.0	12.5	5.0	2.2	70.6
Santa Margarita	I crude	3.8	29.8	9.7	6.6	6.7	10.4	12.4	5.3	2.8	12.4	57.2
	I washed	4.7	37.1	11.4	6.8	6.6	9.0	16.8	5.9	1.2	0.6	35.3
	II crude	1.4	15.3	24.1	14.6	9.6	14.2	10.1	3.9	2.1	4.7	41.4
	II washed	1.8	17.7	22.4	16.7	9.5	11.5	13.2	5.0	1.4	0.7	38.3
Santa Cruz County												
Ben Lomond	I crude				0.8	6.0	45.4	38.8	5.0	1.0	3.0	64.9
	I washed				0.8	5.4	46.3	40.8	5.4	0.8	0.5	61.6
	II crude		0.2	0.1	0.9	20.4	56.2	16.0	2.7	0.9	2.4	56.5
	II washed			0.3	0.7	18.7	58.9	17.8	2.8	0.5	0.3	53.8
	III crude				0.5	1.9	21.8	56.6	12.3	2.4	4.5	761.
	III washed				0.3	2.2	24.0	59.6	12.1	1.4	0.4	69.6
Santa Cruz County												
Eccles	Crude				0.1	31.2	58.8	5.8	1.6	0.8	1.6	51.9
	Washed					24.3	66.3	7.0	1.7	0.4	0.3	50.6
Felton	Crude	2.2	9.8	16.2	33.9	23.0	6.7	3.0	1.6	0.8	2.8	37.4

Table 39. Screen analyses of some nothern California coastal sands.

(Analyses by E. Wayne Galliher)

Location	Sample	Percent retained on sieves										A.F.A. grain fineness number
		12	20	30	40	50	70	100	140	200	—200	
Marin County												
Point Reyes				0.3	3.4	23.1	44.9	23.9	3.3	0.4	0.8	53.5
Mendocino County												
Fort Bragg	I			8.8	13.5	36.3	35.3	5.5	0.6			41.4
	II			7.0	8.6	26.6	47.8	8.9	1.0			45.7
Mendocino	(1)				0.4	9.7	52.2	34.2	3.5	0.1		57.7
Point Arena			4.0	8.5	23.3	32.1	26.5	5.2	0.4			39.2
Pudding Creek					1.3	42.6	50.5	5.5	0.1			46.9
Monterey County												
Del Monte	Coarse		1.0	8.0	38.0	35.0	16.0	2.0				37.0
	Fine				5.0	55.0	35.0	5.0				45.0
San Mateo County												
Half Moon Bay				10.0	28.4	30.8	21.6	7.6	1.5			40.5
Milagra Valley					3.3	26.7	41.0	21.8	6.2	0.9		56.0
Pescadero Creek				8.1	32.9	45.3	12.2	1.4				36.0
Point Año Nuevo					0.5	5.3	42.9	38.6	12.3	0.5		48.0
Sonoma County												
Bodega Head			2.5	6.6	9.0	21.8	38.8	18.9	2.4			48.0

[1] Analysis by Heinrich Ries.

as representative of the northern coastal belt, consists of approximately 50 percent quartz and feldspar grains. The remainder is black shale and brown to black sandstone fragments, along with grains of serpentine. At Fort Bragg shale, sandstone, and serpentine fractions increase to 80 to 90 percent, at Mendocino and Pudding Creek they fall to 35 to 40 percent. All of the sands are typically angular and tend toward wide frequency ranges.

The largest coastal deposits are at Point Año Nuevo, Bodega Head, Point Arena and north of Fort Bragg. Each contains at least 1,000,000 tons. The others are comparatively small.

Data on sands in exposures of the Santa Margarita upper Miocene formation were gathered at nine localities extending from the Ben Lomond area 9 miles north of Santa Cruz to the Reeds—Carpenter Canyon Grade area 4½ miles northeast of Pismo Beach. Included are localities at Big Sandy Creek and Calera Canyon in Monterey County, Santa Margarita in San Luis Obispo County, and Eccles and Felton in Santa Cruz County.[26]

The Santa Margarita sands in each of these areas are mineralogically similar to the present beach sands at Del Monte (Moss Beach). A general ratio of 60 percent quartz to 40 percent feldspar is persistent in both types and consequently comparable silica components of approximately 83 percent are obtained.

From 2 to 12 percent of the Santa Margarita sands, however, will pass the 200-mesh screen, a fraction not present in the Del Monte sands. These fines consist chiefly of white clay and act as a weak binder. For a clean sand, therefore, washing is required and most of the analysed samples have been screened as both crude and experimentally washed material.

The coarsest samples came from the Santa Margarita and Calera Canyon deposits. These show approximately 65 percent retained on the 12- to 50-mesh screens. The finest material occurs in the unusually uniform Reeds and Carpenter Canyon Grade deposits.

Eocene high-silica sands, were sampled in the Nortonville-Somersville area north of Mount Diablo in Contra Costa County and the Cantua Creek area in Fresno County. The mineral content of the samples ranges from 80 percent quartz and 20 percent feldspar to 90 percent quartz and 10 percent feldspar. Chemical analyses of the crude samples average 95 percent silica; of washed samples, 97 percent silica.

In the Nortonville-Somersville area the sands occur alternating with shales through a thickness of 75 to 400 feet. These are in the central portion of an Eocene formation approximately 1000 feet thick.[27]

A representative sample of washed Cantua Creek Eocene sand contained approximately 80 percent quartz and 20 percent feldspar with minor amounts of black carbonaceous chert. The crude material was slightly cemented with iron oxide, but broke down readily in water.

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[26] Unfortunately the localities at which samples were collected were indicated principally on photographs in Galliher's report. These cannot be reproduced here, but are on file for inspection at the California State Division of Mines in San Francisco. It may be assumed, however, that the samples are representative of large bodies or persistent units in their particular areas.

[27] An account of the current sand production in this area is given above under the heading *Pittsburg-Roberts sand.* Sands from this area have been used in glass manufacture but, at present, are not produced for this purpose.

URANIUM

Prepared by W. B. Winston *

OUTLINE OF REPORT

GENERAL DESCRIPTION

Uranium (U) is one of the heaviest known metallic elements, ductile, silver-white in appearance, of high melting point, soluble in acids, and made by the reduction of the oxide. It does not occur free in nature, but is nearly as abundant in nature as copper. In the number of its oxides and the variety of its compounds, uranium rivals manganese; and its metallic conduct places it in rather sharp contrast to molybdenum and tungsten, which are non-metallic in all their chemical properties. The metal has a number of well-defined properties, some of which are: atomic weight, 238.07; atomic number, 92; melting point, nearly 1150 degrees centigrade; density, 18.7 at 13 degrees centigrade; valence 3, 4, 5, and 6; specific heat, 0.0280 at 0.98 degrees centigrade; atomic heat, 6.57 at 0 degrees centigrade; atomic volume, 12.84; mean atomic mass number, 237.977. The metal can take a high polish. The powder burns briskly in air at 117 degrees centigrade to form uranium dioxide. It is stable in dry air, but on standing in moist air it slowly becomes covered with a steel-blue film of oxide. The powdered metal is gray to black in color; it reacts slowly with cold water and more quickly with hot water. It is not perceptibly affected by concentrated alkalis (potassium hydroxide and sodium hydroxide solutions). It combines with fused sulfur and selenium. With carbon the carbide is formed. It dissolves in mineral acids liberating hydrogen during the course of the reaction, also forming a uranous salt. Uranium displaces mercury, silver, copper, tin, platinum, and gold from solution of their salts. It has a great affinity for nitrogen, forming on combination the nitride. It is only very slightly paramagnetic. It is the mother of radium; hence all uranium minerals and salts contain recoverable radium. It has soluble sulfates and chlorides and a great variety of oxides, some acid-forming, some base-forming; and the element may enter secondary compounds.

The oxides of uranium are very important from many standpoints. The mineral often occurs in nature in the form of one or more of its oxides. The best known oxides are the dioxide, the trioxide, and the uranous-uranic oxide. The dioxide, UO_2 (also called uranium oxide,

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uranous oxide, black oxide of uranium), is a dark-brown pyrophoric powder; or copper-red, pyrophoric powder with metallic luster; or black, non-pyrophoric, octahedral crystals; or microscopic, iron-gray needles. It is oxidized to U_3O_8 when heated in air, and is soluble in acids to deep green solutions containing uranous salts. The trioxide, UO_3, or $(UO_2)O$ (also called uranium oxide, uranic oxide, uranyl oxide), is a brick-red or chamois-yellow powder; it decomposes to U_3O_8 and O_2 when heated in air; reacts with water at ordinary temperature, forming uranyl salts; is soluble in bases, forming uranates. The uranous-uranic oxide U_3O_8, or UO_22UO_3 (also called uranium oxide, triuranium octoxide, urano-uranic oxide, uranoso-uranic oxide, green oxide of uranium, uranous uranate), is a dark, olive-green powder, sometimes almost black, which always shows a green streak when rubbed on unglazed porcelain. It is the most important uranium oxide, occurring to a large extent in pitchblende. The oxides are all insoluble in water.

Uranium forms a series of uranous salts and also a series of basic or uranyl salts as well as the tri-, tetra-, and pentachloride. Among the better-known salts are the uranous sulfate $U(SO_4)_2.4H_2O$ (also called uranium sulfate, normal uranium sulfate), in which uranium has the valence of four. It crystallizes with $8H_2O$ as green monoclinic crystals, and is stable in air; when heated it loses its water of crystallization, then decomposes, first to $(UO_2)SO_4$, and finally to U_3O_8. It is soluble in water; is decomposed by water to a basic salt; and forms double sulfates with alkali sulfates. Uranous salts are readily oxidized to uranyl. The best-known salt of uranium is the uranyl nitrate, $UO_2(NO_3)_2. 6H_2O$, also known as "uranium nitrate," in which uranium has the valance of six. (The most stable compounds of uranium are the "hexavalent.") It forms lemon-yellow rhombic crystals; fluoresces green; shows frictional luminosity and detonates when rubbed or crushed. These salts contain the uranyl group UO_2. The uranous salts, of which the best known are the nitrate and acetate, are green; the uranic salts are yellow in color; most of them are soluble in water, and they are remarkable for their extreme fluorescence.

The mass numbers for the three stable uranium isotopes, atoms having different atomic mass, are 234, 235, and 238. Mass 234 is present in proportions of about one to 1700 of 238, the "normal" uranium atom. The intermediate member of mass 235 is of the greater interest since it is a potential source of atomic energy. The proportion in which it is present in all uranium minerals and salts of uranium is one to every 139 of uranium 238. Its only source is uranium minerals. Uranium always occurs in nature in chemical combination with several other elements in compound mineral substances. Uranium ores have been classified as of three general types: (1) The uraninites (pitchblende); (2) the niobium-titanium tantalates of the rare earths and uranium; and (3) secondary minerals.

URANIUM MINERALS

Oxides and Uranates

Uraninite is a general term for crystalline uranium oxide. The UO_2 content is always greater than that corresponding to U_3O_8. Originally occurring probably as UO_2 (ulrichite), it passes in part by disintegra-

tion and auto-oxidation into UO_3 and PbO. Small and variable amounts of isomorphous thoria and rare-earth oxides are present; the gases nitrogen, helium, and argon are also contained in varying amounts up to 2.6 percent. Calcium and water are present in small quantities; iron also, but only as an impurity. Uraninite crystallizes in the cubic system, in modified octahedrons and cubes. Crystals are rare. Specific gravity of crystals is 9.0-9.7, and hardness, 5.5. Fracture is conchoidal to uneven, and the luster is submetallic to greasy. It is velvet black, commonly with a grayish or brownish tinge; and the streak is brownish black or gray, sometimes greenish. Uraninite occurs in pegmatites in many localities and in many countries.

Pitchblende (from pitch, through the German "pech," and German "blenden," to dazzle) is probably a uranium uranate with UO_2 not greater than is required for U_3O_8, with lead as an accumulated end-product. It is commonly hydrous, and thoria and rare earths are absent or occur in traces only. Its U_3O_8 content is 75 to 95 percent. It is cryptocrystalline and amorphous, generally massive and concretionary. Its specific gravity is 6.5 to 8.1; the lower figures (compared with uraninite) are partly the result of hydration and alteration and partly of admixture of impurities. Pitchblende occurs characteristically in metalliferous veins, with sulfides of silver, lead, cobalt, nickel, iron, zinc, copper, and other metals. It has been recorded from pegmatites, possibly because the term pitchblende has not always been used with the discrimination necessary to distinguish the mineral from uraninite. It has been found in many localities and in many countries. Pitchblende is a noteworthy mineral from a physical standpoint. In it helium was first discovered and so were the radioactive elements uranium, radium, polonium, and actinium. The discovery and isolation of uranium and radium in turn led to many important discoveries and advances in chemistry and physics. The scientific conception of the atom has greatly changed since the discovery and study of these radioactive elements.

Other varieties of uraninite are broeggerite, cleveite, nivenite and gummite. Broeggerite (named by C. W. Blomstrand after the Swedish geologist and mineralogist, W. C. Brögger) is a variety of uraninite containing thoria. Its U_3O_8 content is 77 percent. It crystallizes in the cubic system in octahedral crystals. The specific gravity is 8.3-9.0. It occurs in granitic pegmatites. Cleveite (named by A. E. Nordenskiold after the Swedish chemist P. T. Cleve) is a hydrous variety of uraninite in which yttrium earths (about 10 percent) and lead oxide (about 10 percent) are prominent constituents. It carries 57 to 72 percent U_3O_8. Crystals are modified cubes. The specific gravity is 7.49. It occurs in pegmatite in Norway and elsewhere. Nivenite (named after the American, W. Niven, who obtained the material for investigation) is a variety of cleveite less well crystallized and more readily soluble. It occurs massive, with indistinct crystallization. The specific gravity is 8.01, and the hardness, 5.5. It is velvet black and occurs in Llano County, Texas, and elsewhere. Gummite (the name alludes to the gum-like appearance of specimens; Latin, "gummi," gum) is a hydrous alteration product of uraninite and pitchblende with iron, calcium, lead, and some silica. Its U_3O_8 content is 60 to 70 percent. It occurs amorphous in round and flattened gum-like pieces. The specific gravity is 3.9-4.2, and the hardness, 2.5-3. It is reddish yellow to reddish brown, and the streak is yellow. It occurs with uraninite and pitchblende at many localities.

Niobates, Tantalates

The complex primary minerals of the niobates and tantalates of uranium are for the most part rare. Included in these are betafite, samiresite, ampangabeite, euxenite, blomstrandite, samarskite, fergusonite, and some other minerals. They all have common characteristics and are easily recognized because of their high density (over 4), black or dark-brown color, and greasy, brilliant fracture. They are well crystallized, with the exception of euxenite, which is commonly massive. They occur in pegmatites, many are rich in uranium, and may contain thorium in large or small amounts. Betafite (Betafo, Madagascar) is a hydrous titano-niobate of uranium with calcium, iron, and thorium. Its U_3O_8 content is 26 to 30 percent. It occurs with beryl and euxenite in pegmatites and is the most abundant radioactive mineral of Madagascar. Samiresite (Samiresy, Madagascar) is a member of the betafite group rich in lead and water. Its UO_3 content is 21.2. It is found in Madagascar associated with beryl and zircon in pegmatite which contains galena and pyromorphite. Ampangabeite (Ampangabe, Madagascar) is a hydrated tantalo-niobate of uranium, thorium, iron, and rare earths, distinguished from euxenite and aeschynite by its low titanium content. Its U_3O_8 content is 14 to 20 percent. It occurs in pegmatites. Euxenite (named by Scheerer from Greek ''euxenos,'' friendly to strangers, that is, to rare elements) is a hydrous tantalo-niobo-titanate of yttrium, cerium, uranium, and thorium. Its U_3O_8 content is 3 to 19 percent. It is usually found massive; occurs in pegmatites and in concentrates. Blomstrandite (named after the Norwegian chemist C. W. Blomstrand) is a hydrous titano-tantalo-niobate of uranium with calcium and iron. It is a member of the betafite group relatively rich in titanium and tantalum. Its U_3O_8 content is 20 percent. It is not to be confused with the orthorhombic blomstrandine. It is found in octahedral crystals and massive. It occurs with nahlite in Sweden and with euxenite, columbite, and samarskite in Madagascar; also in Valhynia, Ukraine, and the Urals. Samarskite (discovered in the Urals and first called uranotantalite, named by H. Rose after the Russian engineer, Oberst von Samarksi), is a tantalo-niobate of yttrium, cerium, with uranium, calcium, and iron. Its U_3O_8 content is 3 to 16 percent. It is commonly found massive, occurs in pegmatite, and is found in large quantities in the Sankara mine, Nellore district, Madras. Fergusonite (discovered in Greenland, named after Robert Ferguson) is a niobo-tantalate of yttrium, erbium, and cerium, with smaller amounts of uranium, and iron. Its U_3O_8 content is 2 to 9 percent. Crystals are pyramidal or prismatic in habit. It occurs in granites and pegmatites in many localities.

Secondary Minerals

The various uranium-bearing secondary minerals include phosphates, carbonates, arsenates, sulfates, silicates, vanadates, and uranates. They are for the most part characteristically colored bright green or yellow. The most important are carnotite and autunite. Carnotite (named in 1899 in honor of the French scientist, Adolph Carnot) is a hydrous vanadate of uranium and potassium. Its U_3O_8 content is 61 to 67 percent; it contains no thoria. It is found as a crystalline powder or as plates with perfect platy cleavage, often filling cavities, as rough or botryoidal crusts, or as an impregnation in sand or sandstone. It is lemon-yellow or canary yellow, with a green tinge. Autunite (from Autun in central

France) is a hydrous phosphate of uranium and calcium. Its U_3O_8 content is 60 percent. It is found in tabular plates and scales and micaceous aggregates. It is lemon to sulfur-yellow. It occurs in rocks or in pitchblende-bearing veins and uraninite deposits, notably in Cornwall, Portugal, and South Australia. Torbernite (chalcolite) copper uranite (named after the chemist, Torbernus Bergman) is chemically a hydrous phosphate of uranium and copper. Its U_3O_8 content is 55 to 60 percent. It occurs usually in square green tablets and micaceous aggregates; is associated with autunite and frequently in parallel growth with it, but is less common; is also found in uraniferous deposits with other uranium minerals. Tyuyamunite (Tyuya-Muyun, Fergana, Russian Turkestan) is a hydrous vanadate of uranium and calcium. It is probably isomorphous with carnotite; U_3O_8 content is 59 percent. It is found as a yellow powder. It occurs in bands and lenses and lining cavities in gash vein deposits, in Russia, Colorado, Utah, South Australia, and elsewhere. More than a hundred minerals in the world are known to contain uranium; many of these are rare, some very rare.

URANIUM IN ASPHALTIC MATERIAL

The first determination of the uranium content in asphaltic material was made by Street in 1905 when he found 0.377 percent U_3O_8 in Swedish Kolm. He also tested for thorium, but none was found. Since then, the widespread occurrence of uranium in such material has been generally recognized. Hess has described the asphaltic sediments of Utah, and drawn attention to their possible value for age determinations. The anthraxalites (carbon about 95 percent) of Sudbury, Ontario, and of the Mackenzie district, Northwest Territories, occur in pre-Cambrian rocks and contain uranium. Thucholite is a jet-black carbon mineral with a brilliant luster and perfect conchoidal fracture. The ignited ash contains 48.48 percent thoria and 5.8 percent U_3O_8; rare earths of cerium and yttrium groups and silica, and small amounts of other oxides. Uraninite has been found completely embedded in thucholite; and the ash of these, and other specimens intimately associated with uraninite, is itself highly uraniferous. The name consists of the chemical symbols Th, U, C, H, O, with "*l*" added for euphony to the usual ending "ite." The mineral is a primary constituent of pegmatite, associated with uraninite, calcio-samarskite, and crystallite, and is embedded in feldspar, quartz, or mica, in the form of irregular rounded nodules from 1 millimeter to 1 inch in diameter. The material is of igneous origin and has been described from Canada, Sweden, and Russia.

IDENTIFICATION

Before the blowpipe, uranium colors the salt of phosphorus bead a yellowish green in the oxidizing flame and a bright green in the reducing flame. In the borax bead uranium cannot be distinguished from iron. The fluorescent test for uranium has been used for a number of years by the United States Bureau of Mines on various types of samples with very reliable results. It is more specific and sensitive than the usual qualitative tests for uranium, and its simplicity and speed of application contribute greatly to its usefulness. The method is described in United States Bureau of Mines Information Circular 7337 (1945). Since radioactive minerals accelerate the rate of discharge of static electricity from a charged body,

an electroscope is used to detect the presence of uranium. This instrument is described in United States Bureau of Mines Information Circular 6312 (1920). A simple electroscope, which can be made by engineers and prospectors to detect radio-activity, and for qualitative tests, and which gives surprisingly accurate results if handled carefully, is described in Peeles' Mining Engineers Handbook. According to Hess, a test for radioactivity is not a conclusive test for uranium and radium, for thorium also has a disintegration product, mesothorium, which closely resembles radium in its behavior. Tests for radioactivity will therefore show only whether the specimen contains radium and uranium or mesothorium and thorium or all four. The appearance of the mineral will generally determine which of the elements are present, but in case of doubt, the determination requires more elaborate tests, which should be made by an experienced chemist.

OCCURRENCE

Uranium is widely distributed in the crust of the earth, but generally in very small quantities. The element is estimated to constitute 0.008 percent of the earth's crust. It is the twenty-fifth in abundance being next to copper and exceeding tungsten, and it is two times as abundant as zinc, four times as abundant as lead, and many times more common than tin, silver, or gold. It is interesting at this stage to revive the conception that because naturally disintegrating uranium and its derivatives constantly emit heat and are so universally distributed in the earth's crust, they must have profoundly modified the earth's rate of cooling and must still play an important part in maintaining terrestrial heat. It has been suggested that if there is local concentration of radioactive matter in the crust, the radioactively generated heat in those places will gradually accumulate, make the rock-matter molten, and produce bodies of magma. According to this idea the radioactive changes that are going on within the earth produce the heat necessary for volcanic action and even for such vaster igneous manifestations as are represented by the enormous batholiths developed during epochs of mountain making. Uranium and other radioactive chemical elements disintegrate continuously at a measurable rate which seems to be absolutely uniform under all known conditions of temperature and pressure. As soon as a mineral containing uranium has been formed in a rock, helium gas and other products resulting from the breaking down of uranium begin to accumulate; the end product of the change being one kind of lead, which accumulates in the mineral. The ratio of this lead to the uranium steadily increases with the passage of time; and since the ratio of the change has been determined precisely, the age of a uranium mineral can be calculated after a chemical analysis reveals the exact ratio of lead to uranium in the mineral. By means of this method, it has been possible to determine the length of geologic time, estimated to be 2,000 million years.

The known recoverable sources of uranium are so far limited to relatively few countries. The countries which have accounted for commercial production are the Belgian Congo, Canada, United States, Bohemia, Portugal, Australia, Norway, and Sweden. Countries which have had production or are said to be potential producers are Madagascar, Brazil, India, England, Russia, Germany, Bulgaria, and perhaps others. Uraninites (pitchblende, broeggerite, cleveite, and others) are known to occur in Belgian Congo, Canada, Bohemia, Cornwall, Saxony,

Norway, Spain, eastern Africa, Colorado, Connecticut, Texas, Carolinas, and possibly other places. The niobium-titanium tantalates of the rare earths (betafite, samiresite, ampangabeite, euxenite, blomstrandite, samarskite, fergusonite, and others) occur in Madagascar; Brazil, Sweden, Norway, Iceland, Greenland, Canada, Russia, Colorado, and the Carolinas. The secondary minerals (carnotite, autunite, torbernite, and others) occur in Colorado, Utah, Portugal, Cornwall, Spain, France, Saxony, Bohemia, Madagascar, South Africa, Australia, and possibly other places.

PRODUCTION

The richest known deposit of pitchblende is the property of Union Miniere du Haut-Katanga at Shinkolobwe and Kasolo in Katanga, southeast Belgian Congo, central Africa. Uranium ore was first discovered in this metallogenic province in the copper mine of the above company at Luiswishi, just north of Elisabethville, and later discoveries were made at Shinkolobwe in 1915, and later at Kambove, some 60 miles along the railway to the northwest. The uranium ores consist of secondary alteration products, mainly gummite, accompanied by a certain amount of unaltered pitchblende. The list of secondary uranium minerals is long. Summaries of the voluminous literature are most conveniently found in Mineralogical Abstracts (London). The ores which are associated with copper deposits form veins in faulted and crumpled metamorphic rocks; veins are somewhat irregular in distribution and thickness; they have carried as much as 60 percent U_3O_8. Exports (U_3O_8 content) of uranium compounds have fluctuated from a low of nearly 62,000 pounds in 1932 to a high of over 330,000 pounds in 1936. Production in 1942 amounted to 1021 metric tons containing 695 metric tons of U_3O_8. In Canada, the pitchblende deposits discovered in 1930 in the Great Bear Lake region, Mackenzie district, are of considerable extent and importance. The concentrate from the Eldorado mines are estimated to yield 800 to 900 pounds of uranium compounds per ton. The Port Hope radium refinery of this company produced as by-product uranium 540,000 pounds in 1938 and more in 1939. In Bohemia the mines of St. Joachimsthal in the Erzgebirge have long been the world's most famous source of uranium minerals, and until competition from the Belgian Congo began, they were important producers of radium. These deposits have been mined since 1512, and it was in this mining region that Agricola spent the years 1527-33 and secured much information for his pioneer treatise on mining, *De Re Metallica*. The first radium produced by Madame Curie came from these pitchblende ores; and previous to the development of American carnotite deposits about 1914, the bulk of the world's supply of radium came from these ores. By applying the methods based on radioactivity it was determined in 1938 that the age of the uranium-bearing veins in Joachimsthal is 230 million years. The deposits are in mica schists interbedded with limestone; the pitchblende occurs in metalliferous veins with sulphides of silver, lead, cobalt, nickel, iron, zinc, and copper, in places disseminated as small grains in mica schist. The concentrates are about the same grade as those of Katanga; the U_3O_8 equivalent of compounds produced in 1935 and 1936 was about 35,000 pounds. Uranium was reported found near Sumperk, Moravia, in 1934. In Germany previous to 1913 a little pitchblende had been produced from the Erzgebirge in Saxony. These mines are located in the same region and are of the same age and character as those of Bohemia. It was the Annaberg, Schneeberg, and Johanngeorgen-

stadt Kobalts or mine spirits "of ferocious aspect," that Agricola described before 1550 in his *De Animantibus Subterranus,* and of which Paracelsus wrote at length in 1589. In 1927-30 a magnetite mine in the Riesengebirge produced 8 tons of uranium ore; in this, the Bergfreiheits mine, small masses of pitchblende were found at depths ranging from 328 to 492 feet. At Wolsendorf in the Upper Palatinate small amounts of pitchblende and its alteration minerals are found in a very dark purple fluorite, but no production is recorded. Occurrences of uranium minerals are known elsewhere in the country. In England, in Cornwall, pitchblende has been produced and described from several mines. In all cases the uranium lodes cut across the east-west tin and copper lodes, the associated metals being copper, lead, silver, iron, cobalt, and nickel. Autunite, torbernite, and zippeite are usual products of secondary alteration in the higher levels.

In the United States the chief source of uranium is an extensive area in southwestern Colorado and adjoining southeastern Utah. Some deposits in northwestern Arizona were productive from 1910-20. The principal producing localities are all situated in an irregular area, which extends about 100 miles westward into San Juan County, Utah, and 30 miles eastward into San Miguel and Montrose Counties, Colorado, its greatest width being about 50 miles. The ores are carnotite-bearing lenses in Jurassic sandstones. Some of the carnotite is associated with roscoelite, gypsum, copper carbonates, and rare radium minerals. It is found chiefly in sandstone, in some places as an impregnation, or concentrated along cracks or bedding planes or in pockets, where it may be accompanied by petrified wood, bone, or other more or less fossilized organic matter. Most of the ore shipped has carried 2 to 5 percent U_3O_8. The mines are in general small and scattered, and the uranium production has usually been a by-product from vanadium properties owned or operated by the United States Vanadium Corporation, which has plants at Uravan (50 tons) and Durango (100 tons), Colorado; also vanadium plants at Rifle (200 tons) Garfield County, and Uravan (250 tons), Montrose County, Colorado; and the Vanadium Corporation of America, which has plants at Naturita (85 tons), Montrose County, Colorado, and a standby at Monticello, San Juan County, Utah. There also have been several small individual producers. Deposits of carnotite in New Mexico and Arizona, though largely undeveloped, have had some production and are said to be potentially important. Carnotite also occurs at Mauch Chunk, Pennsylvania, and tyuyamunite has been found in the outcrops of copper veins on Red Creek, Brows Hole, northwestern Utah. Autunite reported found in South Dakota and Utah, and in the Ruby Mountains, Nevada, is said to be a potential source of uranium. Pitchblende and uraninite have been found in a number of localities in the United States, but seldom in quantities greater than a few hundred pounds at a time. At Central City, Gilpin County, Colorado, five mines, worked mainly for gold, have yielded pitchblende ores to the extent of perhaps 150 tons or more of low-grade material. In North Carolina and South Carolina, uraninite is found in pegmatites largely altered to gummite, uranophane, and autunite. A few pounds have been saved and sold each year as a by-product of feldspar and mica mining. Occurrences of uraninite in other states appear, so far, to be of scientific interest only. In Connecticut, uraninite is found as a constituent mineral in pegmatites in several feldspar quarries, and in Texas it occurs at Barringer Hill, Llano County, in the form called nivenite, a variety of cleveite. In Cali-

fornia uraninite was found in acicular crystals in a pocket with spongy gold, quartz, and clay, at the Rathgeb mine near San Andreas, Calaveras County. Autunite has been found in the Summit Diggins, near Randsburg. Specimens of yellow autunite associated with green plates of torbernite have come from the northern part of San Bernardino County. No other authentic finds have been recorded, but it is not impossible that uranium minerals in quantity may be found in the state.

Elsewhere in the world there has been small production and many unexploited occurrences have been recorded. In Portugal uranium ores, chiefly autunite, have been mined intermittently for many years. In 1919 nearly 1400 metric tons were produced, with smaller amounts in years following. Stocks of some 1600 tons of vein material, containing 0.5 to 0.7 percent U_3O_8 have been carried at times. The veins are persistent but irregular in width and extent. The richest ore is found between the towns of Guarda and Sabugal near the southern boundary of the granite area in a region highly mineralized with deposits of galena, arsenopyrite, and cassiterite. This region is a plateau, elevation 2700 feet, traversed by a railway from Pompilhasa to Villarformosa and from Guarda to Lisbon. In general the ore is lean. Ore containing 0.3 to 0.5 percent U_3O_8 has been considered profitable, 1 percent good, and 2 percent excellent. Chemical concentration of the ore at the mines proved successful for black minerals but not for typical autunite-torbernite material. The ore is said to be easy to treat. Some concentrates shipped to France have carried as much as 16 percent U_3O_8, but most shipments seem to have been around 1 percent. Notes on the geology of the region were digested by Hess, largely from an article by Dupar.

In Madagascar the production and exportation of uranium ores began in 1912, when 11 kilos were shipped to France. In 1922 almost 16 metric tons were shipped, and in 1923 some 15 tons of betafite and 10 tons of euxenite and monazite were exported. The most important deposits of euxenite are found in Madagascar, occurring in considerable quantity near Antranotsiritra on the river Maevarano, and also in other localities. The uranium minerals are ampangabeite, betafite, blomstrandite, euxenite, fergusonite, samarskite, and samiresite. The uranium-ore areas lie west and southwest of Tananarive, the capital, in the central and south central part of the island. The geology, petrology, and mineralogy of Madagascar form the subject of an invaluable monograph by Lacroix. A review of the radioactive minerals of Madagascar, largely based on the work of Lacroix, has been published in English by Turner. The central and eastern parts of the island are mainly composed of crystalline rocks, metamorphic and igneous. The pegmatites contain many interesting minerals, including various gem stones and radioactive minerals. Uraninite has also been found in the quarry debris of pegmatites. Large nodules with veins of what is probably gummite occur in blocks from the great pegmatite of Malakialina. Associated minerals are tourmaline, beryl, apatite, and titano-niobates. Uranium is also reported to occur in peat. In France autunite occurs at Saint Symphorien and other localities near Autun in Saon-et-Loire. Uranium minerals were discovered about 1827 at Saint-Remy-sur-Duralle, and discovery of torbernite (chalcolite) was reported from the Puy de Dome region in 1928. Lead, zinc, copper, and radioactive ores occur in the Arrondissement of Villefranche, Department of the Rhone. No production in the country is reported. Betafite ores are obtained from Madagascar, and torbernite has come from French Indo-China; autunite, from Portugal.

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Uranium-bearing ores are known in two principal areas in South Australia. The Mount Painter field in the northern Flinder's Range was discovered in 1911 and is the more important of the two. The main mine workings are about 80 miles by road northeast from Copley on the Great Northern Railway and 374 miles from Adelaide. The radio-active minerals occur in "basic" pegmatites, the uranium ores are mainly torbernite and autunite associated with carnotite, uranophane, gummite, fergusonite, monazite, and titaniferous and manganiferous iron ores. The field is extensive, but not high grade. The best ore now available appears to carry 1.74 percent U_3O_8, and most of it is much lower grade. Reports indicate that ore containing 3.3 percent U_3O_8 has been produced. The ore minerals are irregularly distributed, occurring in small seams and veins, sometimes as small scales thickly or sparsely disseminated or only as a coating along joint planes. Similar deposits occur at Radium Hill, near Olary in the older Broken Hill complex, about 50 miles from Broken Hill and 12 miles from Cutana siding on the railroad. Uranium ore occurs in an ilmenite-rich quartz-biotite pegmatite and is described as "a mineral complex consisting of an intimate admixture of ilmenite, magnetite, rutile, carnotite, and a mineral which is probably titanate or silica-titanate of rare-earths, etc." Both fields have had production at various times. In Western Australia fergusonite and euxenite occur at Cooglegong, but no considerable production is expected from this source. It was claimed in 1945 that one of the world's largest uranium deposits was discovered near Stanthorpe, Queensland. The ore was said to carry up to 3 percent uranium. In South Africa, in Swaziland, euxenite and priorite, and other minerals of the titano-tantalo-niobate groups occur in pegmatites and in derived stanniferous gravels. They have been described by Rogers. Rogers also mentions columbite and tantalite from Little Namagualand. Farther north the pegmatites of Damaraland, Southwest Africa, carry uranium-bearing niobo-tantalate and rare-earth minerals, including blomstrandite, described by Wagner. Of interest also are the discoveries of uraninite in South Africa. Deposits have been found in northern Transvaal and in the Gordonia district of the Cape Province. In India the mica pegmatites of the Gaya district of Bihar have yielded uraninite, "uranium ochre," and torbernite, and also samarskite, gadolinite, and other radio-active rare-earth minerals. A radio-active columbite from Gayo contained U_3O_8. The uraninite is found occasionally in nodular masses embedded in feldspar or in the books of muscovite for which the pegmatites are worked.

In Russia systematic exploitation of rare elements started in 1925, with the foundation of a central organization for handling all questions pertaining to them, which now functions under the name of "Sojusredmet." This organization concerns itself with the exploration, as well as the study of scientific experimental and plant questions regarding uranium and thorium and other combined elements. It also embraces the scientific experimental institute for rare elements "Giredmet," with its branches at Odessa and Aserbaidshan, as well as a number of mining enterprises in the Urals, East Siberia, Turkestan, and the Ukraine, and a plant for rare elements at Moscow. In addition, over half a dozen scientific institutes concern themselves with rare elements. Russia's Rare Metals Works in Moscow isolated radium from tyuyamunite ore mined at Tyuya Muyun, Fergana, Russian Turkestan. In 1934 a deposit of uranium ore containing 3 percent U_3O_8 is said to have been discovered

100 kilometers northwest of Fergana, at Taboshar. The source of Russian radium has been the Tyuya Muyan deposits in the foothills of the Altai Mountains in Southwestern Fergana, approximately 60 kilometers east of Skobeles and 55 kilometers south of Andijan. The deposit consists of barite veins carrying uranium in a very complex ore. The Fergana deposit was discovered many years ago and was worked by the Chinese in a primitive way for copper. Previous to 1914, 1000 tons of ore were produced, of which 700 tons were utilized for the extraction of uranium, copper, and vanadium. In 1922 ore reserves in sight were over 5000 tons. In 1924 and in 1945 Russian geologists reported the discovery of a large deposit of uranium in the Caucasus, said to carry 3 percent U_3O_8 and to be larger than the Tyuya Muyun and Taboshar fields. The ores are believed to resemble the carnotite ores of the United States. Other occurrences in Russia are the uranium-vanadium minerals found in small quantity west of the Fergana deposits near the village of Patekhino in the Minusnish district of the Yenisei government. Radioactive titano-tantalo-niobates of yttrium and the uranium minerals euxenite, blomstrandite, and samarskite, occur in a granite pegmatite in Valhynia the Ukraine, Western Russia, between Lemberg and Kiev. A search for radioactive minerals in Carelia on the Arctic coast east of Sweden in 1925 revealed uraninite in several pegmatites. In the Urals blomstrandite and other uranium minerals are reported found.

In Bulgaria announcement was made in 1934 of the discovery of "very extensive deposits" of autunite near the village of Streltscha. It is said that work on the deposit begin 2 years previously. In Rumania, at Rezbanya, uranite occurs associated with metallic minerals. In Sweden various uranium minerals occur in pegmatites and granites, including fergusonite at Ytterby; euxenite, blomstrandite, and samarskite in scattered localities; polycrase in Smaland; and uranium has been recovered from coal and oil shale. In Norway, crystals of uraninite occur in granites; other varieties are broeggerite, cleveite, euxenite, samarskite, and polycrase in granites and in pegmatite veins in various localities, notably at Arendal in Aust-Agder, and at Moss. Production, if any, from the above countries has been very small. In Japan, fergusonite and possibly other uranium minerals occur. In Brazil the known uranium minerals are samarskite, polycrase, fergusonite, betafite, and torbernite. No production is recorded from these and other countries.

PROSPECTING

Since all uranium ores are "spotty" and irregularly distributed in scattered and usually relatively small deposits, prospecting constitutes in all localities an important factor even after commercial development has begun. Many of the uranium minerals are brightly colored, either yellow or green, and even the black varieties have a characteristic appearance, so that ore bodies are readily recognized if they outcrop. More often they do not outcrop and the search for ore involves a careful study of the geological conditions. Local differentiations in the appearance or associations of the minerals in the vein filling, properly interpreted, may lead to the discovery of ore shoots. No rule in prospecting can be given, except that good judgment might be shown in choosing a favorable location. In prospecting and in delineating ore bodies, all the usual methods may be employed; but even results from core drilling are uncertain, unless holes are closely spaced, for there is usually little continuity to the deposits.

The Geiger-Muller counter is of particular interest to the prospector for uranium ores. In conjunction with a geological investigation of the silver-bearing veins at Contact Lake, Northwest Territories, Canada, a survey was made with a Geiger-Muller counter of the gamma-ray emissions from rocks in the vicinity of the mine workings. The instrument, as adapted for field use, is described by Ridland; the technique of transporting and operating the instrument is outlined; and the general precautions to be observed are discussed. The results obtained at Great Bear Lake show that the instrument is capable of detecting not only a pitchblende ore shoot in a shear zone, but also the mildly radioactive ''host rock'' at a considerable distance from the ore body.

MINING, CONCENTRATING, AND MARKETING OF ORE

Large-scale modern methods are not practicable in mining uranium ores, because of the patchy nature of the deposits. Gophering appears to be the only economical means of working, and hand-picking plays an important part in sorting the ore. Most uranium ore minerals are relatively brittle, and they tend therefore to form enriched dust when crushed. In Cornwall mechanical ore treatment has consisted of simply drying, crushing, and screening on a fine screen. Table concentration did not prove satisfactory in Australia. The ores of the Eldorado Gold Mines, Ltd., Northwest Territories, Canada, which contain pitchblende, native silver, and chalcopyrite with various iron, cobalt, nickel, molybdenum, bismuth, lead, zinc, and manganese minerals in fine-grained silicious altered sedimentaries and volcanic rocks, are treated by means of crushing, screening, grinding, classification, picking, and gravity concentration and flotation. Considerable work has been done by the United States Bureau of Mines on the concentration of uranium minerals, the results of which are given in Bulletin 103, pp. 61-76, by Kithil and Davis. Successful tests were made of wet methods, using carnotite ore of only 0.75 percent U_3O_8 content. Concentrates of 2.25 percent were obtained by simply running the ground ore (80 or 100 mesh) through a Dorr classifier and saving the slimes.

The problem of concentrating carnotite has been reviewed by Doerner. Carnotite ore is a sandstone impregnated with carnotite and related minerals. Organic matter such as the remains of trees were often the cause of deposition of ''bug holes'' of nearly pure mineral, but as a rule the carnotite forms as incrustations on the sand grains on exposed faces in joints and fractures of the rock, and less often as individual grains. As the carnotite is relatively soft, most ores are easily crushed to the size of the sand. These ores are concentrated by a mechanical separation of the dust from the coarser sand grains. This may be accomplished either wet or dry, the wet methods being the more effective. In the dry method, the dry crushed ore is agitated in a current of air to separate the dust from the sand. For good results the sand grains must be scoured clean from adhering mineral, with minimum crushing of barren grains. Ordinary crushing or grinding equipment is not well adapted to this operation because it is designed to crush or pulverize but not to scour through attrition. The impact or beater mill used in the Bureau of Mine's work is probably the best standard type for the purpose.

A semi-commercial test was completed early in 1921, on the dry concentration of low-grade carbonaceous ores from the Temple Mountain area near Green River, Utah. Because of the large amount of organic

material present, these ores are among the most difficult to treat by either mechanical or chemical methods. Much of the organic substance resembles a tough asphalt and is so closely associated with the valuable minerals that both mechanical and chemical disintegration are obstructed. It was found that the difficulty could be overcome by roasting, a method later patented. Roasting not only removes all organic matter and moisture, but it also causes chemical changes which disintegrate the physical structure of the valuable minerals, reducing their powers of cohesion and adhesion so that they are more easily reduced to dust. A specially designed machine was constructed to scour the sand and separate the dust. It consisted of a long metal trough provided with a tight hood and having a double row of agitating paddles, which were mounted on parallel horizontal shafts revolving in opposite directions. Roasted ore, fed continuously into one end of machine through a sealed hopper, was tossed about by action of paddles. Jets of compressed air in bottom of trough blew off the dust which was collected in the usual arrangement of cyclone dust collector and bags. The clean scoured sand was discharged through a sealed overflow at the end of the trough opposite the feed hopper.

For the mining of uranium ore, application for a license should be made to the United States Atomic Energy Commission, Oak Ridge, Tennessee, and/or United States Atomic Energy Commission, Information Office, 1901 Constitution Ave., N. W., Washington, D. C.

> "Source material subject to control including export control by the Commission includes all material which contains as much as one twentieth of one percent (0.05 percent) by weight of uranium, thorium or any combination of these elements. After April 1, 1947, no person unless licensed by the Commission may transfer, deliver, receive, or be in possession of, or export from, the United States any source material as defined above after removal from its place of deposit in nature."
>
> "Persons who pass or obtain possession of or title to source materials, as listed below, are required to report these materials to the Commission within 30 days of the effective date of the regulations (or within 30 days of obtaining possession of, or title to, whichever is later): Raw (non-processed), source material after its removal from its place of deposit in nature, which contains 10 pounds or more of uranium or thorium."

As in the United States, virtually all countries that possess radioactive minerals have established controls over movements of such materials or have nationalized the deposits. In the United States, including Alaska, all public lands that contain deposits of radioactive minerals were withdrawn by Executive Order 9613, September 13, 1945.

URANIUM ORE PURCHASING SCHEDULE

The schedule as issued by the Vanadium Corporation of America, May 22, 1947, for uranium oxide, U_3O_8, contained in ore delivered to the company's stockpile in Colorado (plant at Naturita, Montrose County), provided such ores contain a minimum of two-tenths of 1 percent of U_3O_8 is as follows:

Contained U_3O_8 in percent	*Value paid per lb. of U_3O_8 in ore*	*Contained U_3O_8 in percent*	*Value paid per lb. of U_3O_8 in ore*
Under 0.2	None	1.01-1.25	$0.70
0.20-0.30	$0.35	1.26-1.50	0.80
0.31-0.40	0.40	1.51-1.75	0.90
0.41-0.50	0.50	1.76-2.00	1.00
0.51-1.00	0.60	2.01-over	1.10

USES AND TECHNOLOGY

The uses of uranium in this country were, until 1943, practically limited to glass and ceramic industries, in which sodium uranate and the U_2O_6 oxide are the usual vehicles for introducing the element. In glass or ceramic glazes, uranium produces fluorescence, or yellow brown, or black coloration, depending on amount and color of the added ingredients. Large quantities were employed to give a creamy tint to heavy glazed building tile for facing large structures, cornices, etc. A small quantity of salts were used in chemistry. As a deoxidizer for steel, ferro-uranium proved less suitable (largely because of volatility of uranium) than other and less expensive alloys. Uranium has also served as a catalyzer in the Haker and other nitrogen-fixation processes. The carbide U_2C_5 is strongly pyrophoric. There were few if any practical uses for uranium as a metal. The consumption rarely was under 200,000 pounds (oxides and salts), between the late twenties and 1940, and in a few years it was virtually double that quantity. Control of uses of uraniferous materials was made effective under W.P.B. Conservation Order M-285 in January 1943, and is still in effect. Radium has been used principally in therapeutics. It is a standard remedy for removal of birthmarks, care of fibroid tumors, and alleviation or cure of certain cancers. It has also been employed successfully in treatment of certain cases of leukemia, tubercular glands of the neck, and other diseases. The service the discovery of radium has rendered is very great—to science, and thus the electrical industry, and in the new conception of the constitution of matter. Radium is now used in the detection of flaws in steel. For this purpose, a tube containing radium is placed on one side, and a photographic plate on the other side of the metal; flaws are revealed on the developed plate by differences in exposure. This practice has been described in considerable detail by V. E. Pullin. The use of radium for ionizing air, making it a conductor to prevent accumulation of static charges of electricity in rolling or molding rubber, has been reported. It is also reported advantageous to add radium salts to spinning solutions from which rayon fiber is made, presumably to prevent the accumulation of static electricity and the consequent standing apart of the fibres. In this connection, polonium, said to be worth some $2,000,000 an ounce, has been used by Firestone Tire and Rubber Company in spark-plug electrodes, to ionize the air gap and speed the passage of a hot spark under all temperature conditions. Polonium and ionium may be extracted from Canadian ores. Ionium, which is about 40 times as abundant in these ores as radium, has long been used in small quantities in scientific work, notably at meteorological stations.

In very recent years the use of radium in medicine has been overshadowed by its industrial use for radiography and otherwise, by consumption of luminous paints. A special use of radium and beryllium is as a source of neutrons in pilot-scale reaction piles. It is said not to be improbable that subcritical quantities of U^{235} and platinum may have important research if not industrial value. Broadly, these are thermal energy and direct radioactive products or isotopes that may be made by introducing foreign material into reaction piles; the heat output is very great, but many problems in connection with its utilization remain unsolved. It is improbable that it soon could compete economically with the common fuels, and for the present it could be developed only in massive plants because of the heavy radiation shielding required.

A great supply of radioactive products exists in uranium fission plants. It is said that enough is known of these virtually new products to indicate that the science of metals stands at a new threshold, with these materials as tools, and new vistas are opened in chemistry, biology, and therapy. It is reported that the Monsanto Chemical Company is to supervise the design, construction, and operation of a plant planned solely as an atomic power plant, and that the Allis-Chalmers Manufacturing Corporation, among others, will likewise manage broad-scale research for, or in conjunction with, the government.

As regards the technology of uranium, until 1942 pure uranium had not been made. Details of methods later developed have not been disclosed. Earlier methods were reduction of uranium chloride by calcium and direct oxide reduction with calcium or calcium hydride. These methods produced pyrophoric and very reactive powders of about 99.8 percent purity. Highly pure metal had been made by fluoride (KUF_5) electrolysis, but as it depended on sunlight for a photochemical reaction the method was not suited to volume production. The National Bureau of Standards then perfected an ether extraction method for treating uranyl nitrate that furnished a satisfactory pure brown uranium dioxide (UO_2). This oxide was used as a base for the potassium uranium pentafluoride and the uranium hexafluoride used for isotope separation and also as a source of the metal. Since U^{235} is chemically identical with the major isotope U^{238}, recovery methods were physical in nature. Principal methods employed were gaseous diffusion through porous barriers, thermal diffusion, and electromagnetic separation in cyclotrons. A centrifuging process also was used but only for pilot-scale operation. The first pure chemical compound of plutonium was prepared in August 1942. This new metal results from neutron captured by U^{238} becoming the isotope U^{239}, which rapidly decays with two successive beta-particles (electron) transformations to become neptunium (Np^{239}) and then plutonium (Pu^{239}). Plutonium is an alpha particle (helium nucleus) emitter and eventually becomes U^{235}. The decay rate is, however, so slow that it may be considered a stable element, but like U^{235} is readily fissionable. Separation of plutonium from uranium apparently was carried out by coprecipitation with a carrier analogous to precipitation of radium-uranium separation, followed by successive dissolutions of the precipitate and reprecipitations, until unwanted fission products were reduced to a satisfactory level. This involved about 30 major chemical reactions and hundreds of operations all remotely controlled. Final purification, melting, casting, and forming were conducted at the New Mexico laboratories.

The quantity of fissionable isotope U^{235} and plutonium produced has not been made public by the government. From the practical standpoint, production of the new element plutonium, which was begun on a large scale at Hanford, Washington, in September 1944, though an intricate and difficult problem, is more efficient than the uranium-isotope separation. Plutonium production piles were still in operation in May 1946. Some 150 isotopes of about 35 elements in the atomic-mass ranges 83 to 115 and 127 to 154 were made in the U^{235} Pu^{239} fission. Among them were elements 43 and 61 (masurium and illinium) whose earlier isolation has been questioned. Of these, according to the Smyth report, about 20 are significant concentration, with the most abundant less than 10 percent of the aggregate. The half lives (the period in which one-half

disintegrates) of these intermediates range from a small fraction of a second to a year or more. Some are gaseous and are wasted into the atmosphere; others are retained in the effluent from the units in which the plutonium is extracted from the reacted uranium slugs and are held in storage basins. Presumably a substantial quantity of relatively long-lived radioactive products will have been accumulated.

The discovery or development of two new elements of atomic numbers 95 and 96, for which the names americium and curium have been proposed, was announced by Seaborg. Like neptunium and plutonium, they are radioactive. They have not been found in nature; until 1942 no evidence of the natural existence of neptunium and plutonium had been found. With the knowledge of the characteristics of these elements, a careful search revealed certain alpha activity in pitchblende.

In radioactive substances, the so-called alpha-rays are streams of positively charged atoms of helium explosively emitted from the parent atom with velocities ranging from 5 to 15 percent of that of light. Beta-rays are streams of electrons, each having a mass equivalent to 1/1834 of that of the hydrogen atom. Beta particles are expelled with velocities ranging from 33 to 99 percent of that of light. Gamma-rays are electromagnetic pulses of the same nature as x-rays, but characterized by having shorter wave-lengths over the greater part of their range. They accompany the emission of beta-rays and are propagated with the velocity of light. By the impact of such particles on otherwise stable atoms, elements have been transmuted, a feat which was long deemed impossible. The nucleus of an atom though of almost vanishing dimensions, in comparison with the atom, is itself of very complex structure; in size, it is one one-thousandth of the diameter of an atom, which itself is only a hundred millionth of a centimeter in diameter. Until the discovery of nuclear fission in 1939, physicists knew only of reactions producing small changes in the mass number and atomic number. In the nuclear reaction of fission the nucleus breaks into two approximately equal parts. In the case of uranium the immediate products of fission are two elements, one of which is close to barium and the other close to krypton in the periodic table.

Tremendous energy is released in nuclear fission. The term "fission" is taken from a biological expression meaning "reproduction by spontaneous division of the body into two parts, each of which becomes a complete organism." The sum of the true masses of the product nuclei is definitely less than that of the nucleus from which they came. The fragments of the nucleus fly apart with such tremendous velocities that the sum of their masses, in the sense of the theory of relativity, just exactly equals that of the original nucleus. Another feature of nuclear fission is the fact that whereas one neutron is required to produce a fission, several neutrons are themselves produced by the fission; these break off from the product nuclei subsequent to the fission reaction itself. Under favorable conditions it is possible for these secondary neutrons to stimulate further fission reaction and thus an explosion.

HISTORY

In 1789 Klaproth, who made many brilliant contributions to analytical and mineralogical chemistry, discovered the element uranium in pitchblende, then thought to be an ore of zinc, iron, tungsten, or chromium. He named the new element in honor of Herschel's then recent

discovery of the plant Uranus. Other investigators immediately confirmed the existence of uranium. In attempting to isolate the metal, just as Hjelm had prepared metallic molybdenum, Klaproth obtained a black powder with metallic luster, the elementary nature of which was accepted by chemists for more than 50 years. It is interesting to note that Klaproth termed his new element ''half-metallic'' although this was not really indicated until 150 years later in studies on crystalline structure by advanced methods. In 1823, J. A. Arfwedson on reducing the green oxide of uranium obtained a brown powder which he took to be the metal, which now is known to be uranous oxide UO_2. In 1841 Peligot prepared metallic uranium by reduction of uranium chloride with sodium in a closed platinum crucible. In 1882 Zimmerman used a similar method; Moore in 1923 used the same method to obtain metallic uranium but he also used a steel bomb. Moissan in 1896 tried producing uranium metal by electrolysis.

The radioactive properties of uranium remained undiscovered for 107 years after Klaproth's discovery of the element. It then turned out that the choice of name had been almost prophetical. The planet Uranus had been discovered by Herschel in 1781, and Bode suggested it should be called after Uranus, the Father of the Gods. Uranium as a natural element has a unique title to an illusive name of this order. In 1896 Henri Becquerel discovered that the metal uranium as well as all substances containing it, continuously emitted rays evidently inherent in the uranium atom, which could penetrate matter, and affect a photographic plate and which also discharged a gold-leaf electroscope. This new property was called ''radioactivity.'' These fundamental observations of Becquerel, which happened at a critically favorable moment, inaugurated an accelerating harvest of outstanding discoveries without parallel in the history of scientific investigation. In 1898 Marie Curie discovered the element ''radium'' in pitchblende, in barium-residues, and the element polonium in bismuth-residues of the mineral. Shortly afterwards Debierne separated ''actinium'' from thorium-residues of pitchblende. Strictly pure radium chloride was first produced in 1902, and since that time the knowledge of radioactivity has developed rapidly.

The investigation of the properties and nature of the spontaneous radiations of uranium and of the other radioactive elements, known collectively as the Becquerel rays, is largly due to the scientific genius of Sir Ernest Rutherford. In 1899 he classed them as alpha, beta, and gamma rays. On an average, gamma-rays are about a hundred times more penetrating than beta-rays and beta-rays in turn about a hundred times more so than alpha-rays. Curie and Laborde in 1903 observed that radium is constantly giving out heat. This discovery is of fundamental importance to geology and to physics. The sources of this thermal energy, over a hundred calories per hour per gram of radium, lie in the kinetic and electromagnetic energy of the rays. These phenomena appear to continue unceasingly. Year after year the spontaneous production of helium goes on accompanied by an unfailing evolution of heat. The chemically inert gas known as ''radium emanation,'' or ''radon,'' is the atom that remains after a helium atom has separated from a radium atom. Few elements have had so remarkable a history as regards the details of their discovery as helium. Helium was first discovered in the sun by Lockyer during the eclipse of 1868, and it was not until

1895 that it was detected in terrestial materials, by Ramsey, who identified it in uranium.

In 1902 Rutherford and Soddy advanced a simple quantitative all-embracing theory known as the "disintegration theory." The fundamental assumption of this theory is that the number of atoms of a radio-element disintegrating at any instant is always proportional to the number of atoms of that element which are present. The whole series of genetically related elements from uranium downward is called a "disintegration series." Three such series are known, the uranium-radium series, the actinium series, and the thorium series. In each of these every element (after the first at head of series) is produced by the one preceding it, and is the parent of the one that follows, until the series comes to an end-product that is stable. When equilibrium between formation and transformation has gradually been established, a given quantity of radio-element A produces as many atoms of B as B produces of C, and so on through the series. The time taken to reach equilibrium throughout a series is necessarily very long, and it is only in old radioactive minerals that have remained uncontaminated by weathering or percolating waters that a complete series with each element in its proper proportion can be found. In most secondary minerals, like autunite, the age of which may not exceed a few thousand years, the condition of equilibrium will not in general have had time to become established. This accounts for the fact that the ratio between radium and uranium in certain recent minerals may depart considerably from the constant ratio found in older undisturbed minerals.

The modern theory of the atom has developed from a brilliant hypothesis of atomic structure advanced by Rutherford in 1911. Niels Bohr, of Copenhagen, in 1913 put forward a theory which combined Rutherford's model of "nuclear atom" with the quantum theory of energy which had been enunciated by Plank to explain limitations of the classical electromagnetic theory. The resulting Rutherford-Bohr model of the atom proved to be of the greatest value in explaining the results of experimental work in every branch of physics and in particular the relationship between the different elements as regards their ordinary physical and chemical properties.

Boltwood, in 1907, found that thorium and ionium were chemically inseparable, despite the obvious difference between their atomic weights. Marckwall and Keetman, in 1910, after 2 years of work of unrivaled delicacy proved the complete chemical identity of thorium and ionium, and Hahn showed that radio-thorium also has identical chemical properties. The individual members of a single chemical type are now referred to as "isotopes"; this name having first been suggested by Soddy in 1910, as a result of studies of the decay products of the natural radioactive elements, to express the fact that they occupy the same (isos) place (topos) in the periodic classification. Aston, at Cambridge, followed up work which had been started by J. J. Thompson (1906-13) and in 1919 developed the so-called "mass-spectrograph." Urey and Brickwedde and Murphy of Columbia University discovered deuterium in 1932. They showed that hydrogen itself is not a single element but contains a small amount of an isotope known as "heavy hydrogen" or deuterium; the corresponding nucleus is called the deuteron.

The first decisive steps in the solution of artificial disintegration of atoms was taken by Rutherford who in 1919 produced the transmutation

of nitrogen. Further transmutations were made by Rutherford and Chadwick in 1919-23. They found that many other light elements could be transmuted in a similar way to that of nitrogen. Together with other physicists, they attacked many other questions concerning the properties of atomic nuclei and their structure, laying the experimental foundation for a whole new branch of physics, now known as nuclear physics.

The discovery of the neutron by Chadwick in 1932 was of fundamental importance. It was at once realized that neutrons, together with protons, were likely to be the ultimate constituents of the nuclei of atoms of all elements. The discovery of the neutron was of even greater practical importance in that its lack of electric charge made it an ideal projectile for carrying out nuclear transformation. The use of neutrons as a means of exploring the structure and reactions of atomic nuclei was taken up actively in physics laboratories throughout the world. The "cyclotron" was invented in 1934 by E. O. Lawrence of the University of California, Berkeley, for which work he was awarded the Nobel prize in physics for 1940. Neutron sources can be made by the use of this machine which employs the principle of multiple accelerations. An important contribution to the new science of nuclear physics was made by Joliot and Irene Curie-Joliot by the discovery in 1934 of artificial radioactivity. The result of this work stimulated similar experiments all over the world. Enrico Fermi began an intensive study in 1934 of the reactions produced when the nuclei of all species were subjected to neutron bombardment. The result of this work showed that new isotopes were formed which were unstable and were subject to radio-active decay.

Nuclear fission was discovered by Professor O. Hahn and Dr. Strassman in January 1939. This finding is said by physicists to promise to exert a greater influence on the shape of things to come than any other discovery in the past century. Immediately following publication of this discovery, Dr. O. Frisch of Copenhagen and Professor Lise Meitner, pointed out that this could only mean that, when uranium was bombarded by neutrons, a nuclear reaction took place of a kind entirely different from any so far studied and that the uranium nucleus split into two parts of roughly equal mass. This phenomenon for which they proposed the name "nuclear fission" could be explained in terms of the theory of nuclear reactions developed by Professor Niels Bohr in the preceding years. They also said that fragments of the uranium nucleus would fly apart with great energy. Confirmation of the reality of the fission process with uranium and the great release of energy accompanying it was obtained by Professor Joliot in Paris independently, and at nearly the same time, and by other physicists throughout the world as soon as the original work was known to them. Experiments of the same type were carried out in the United States by Anderson of California Institute of Technology, Fermi, now of Columbia University, Hanstein, Szilard, and Zinn and others.

SELECTED REFERENCES

Much has been written on uranium and uranium physics. For more complete discussion the following references, some of which give extensive bibliographies, have been selected.

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MANNER OF LOCATING AND HOLDING MINERAL CLAIMS IN CALIFORNIA*

By A. H. Ricketts
(with revisions by C. A. Logan)

OUTLINE OF REPORT

* These notes are based upon *American Mining Law*, by A. H. Ricketts, State Division of Mines Bulletin 98, 1931 (republished as Bulletin 123, 1934), and briefly outline the salient information needed by the average prospector and claim owner in initiating and maintaining his possessory rights to mineral ground.

LANDS OPEN TO LOCATION

(Sec. 2319, Revised Statutes of U. S.)

All valuable mineral deposits in land belonging to the United States, both surveyed and unsurveyed, and the lands in which they are found, are free and open to exploration, occupation and purchase, except that aliens may not obtain patent. This includes mineral land within a national forest, the unpatented parts of a congressional grant to a railroad company (except iron and coal), or of an unconfirmed Mexican grant (to abide the final determination of the validity of the grant), also land within the limits of an unpatented townsite, or when known to be mineral at the date of the application for patent therefor, or an unlocated or unpatented "known lode" within the exterior limits of a patented or unpatented placer mining claim [1] or mineral lands within an abandoned military or Indian reservation or mineral lands restored to the public domain.

Land valuable for its mineral deposits is land which contains minerals in sufficient quantities to justify exploitation and development. The mineral deposits may be metalliferous such as gold, silver, and other metals, or nonmetalliferous such as alum, amber, building stone, diamonds, gypsum and like substances; but under more or less recent congressional legislation, popularly known as the "Leasing Act," lands known to contain coal, petroleum, oil shale, potash, phosphate, sodium salts (except common salt, on which one claim only may be located) can not be located nor patented under the lode or placer laws but are obtainable under lease, subject to the regulations and control of the Secretary of the Interior. But the possessory right to a location made prior to the passage of that act is not disturbed by its provisions.

Under the "Stock-Raising Homestead Act" there is a severance of the surface and mineral deposits and the latter may be located and worked in accordance with the mineral land law, with the right to enter and occupy so much of the surface thereof as may be required for all purposes reasonably incident to the mining or removal of the mineral; first, upon securing the written consent or waiver of the homestead entryman or patentee; second, upon the payment of damages to crops or other tangible improvements to the owner thereof, where agreement may be had as to the amount thereof, or, third, in lieu of either of the foregoing provisions he must execute a good and sufficient bond or undertaking to the United States for the use and benefit of entryman or owner of the land to secure the payment of damages to said crops and tangible improvements as may be determined by a court upon proceedings duly had and taken. All this seems to be giving a thing with one hand and taking it away with the other.

LANDS NOT OPEN TO LOCATION

Land is not subject to mineral location when lying within a subsisting Indian, military, naval, national park, national monument (except Death Valley National Monument), reservoir reservation, power site, when withdrawn from sale by authority of congress, or by an executive order express or implied; when situated below high tide; the bed of a navigable river; a lake bed (except Searles Lake in San Bernardino

[1] But no one may go upon a valid placer claim to search for a vein, without the claim owner's permission.

County); coal or iron lands within the limits of a congressional land grant to a railroad company, or within its rights of way, or its indemnity limits; land within the limits of a congressional land grant to a state after approval of survey or certification by the land department; land which is occupied under color of title (unless it can be done peaceably); land which has passed into private ownership, patented land deeded to the state for unpaid taxes, land in national forests acquired under the Act of March 1, 1911 (Weeks Act); and land in a patented townsite after application for such patent has been made.

MINING CLAIMS WITHIN NATIONAL FORESTS

Generally speaking vacant United States land within the boundaries of national forests is open to location and entry for mining purposes under the general mining laws, subject to the jurisdiction of the United States Forest Service. There is much doubt and confusion as to the extent of this jurisdiction. Over certain lands (e.g., those obtained under the Weeks Act) jurisdiction is definite, and mining claims cannot be located on such land, but the Secretary of Agriculture is authorized, under regulations prescribed by him, to permit prospecting or mining there. All prospectors in the national forests should acquaint themselves with the Forest Service regulations. In general, the Forest Service is concerned primarily with preservation and improvement of forests, watersheds and range lands, and in California especially, with its long dry season, attention is given largely to fire prevention, through control of access to certain areas and control of use of explosives, fire permits, etc.

The trend of court decisions in disputes between the Forest Service and bona fide mineral locators has been to protect the miner in the full use and enjoyment of his claim. He should be prepared, however, to prove by definite assays, sampling or actual production records that the land embraced in his claim is not merely mineral-bearing, but is or promises to be more valuable for mining than for any other purpose. This is made necessary by the present policy of the Forest Service.

MINING LOCATIONS

A lode location can legally cover only a vein of quartz or other rock in place, and a placer location covers all other types of mineral deposit. Although either type of location if legally completed is presumed to give exclusive right to the surface except in special cases, there is no legal prohibition against the placing of both lode and placer locations on the same land by one locator, if conditions warrant. An example would be a partly eroded gold lode where the soil might carry free gold and the lode might be exposed by placer mining. Errors of any kind in a location which might render it void may be corrected by an amended location, in the absence of any intervening right. A "known lode" in a placer claim, if not specifically mentioned by the applicant for placer patent, and paid for separately, would become thereafter subject to lode location by another if this can be done peaceably, but blind veins pass to the placer claimant, without extralateral rights. No person may enter and prospect for such veins without the consent of the placer claimant.

A mill-site may be located on not over 5 acres of nonmineral land, not adjacent to a vein or lode, or it may be located or may be "scripped"

upon lands which are prima facie mineral but which in fact are valueless as such.

A tunnel-site claim may be located for the purpose of prospecting for blind veins not previously known to exist along the location line of the tunnel, for a maximum length of 3000 feet. The locator has the exclusive right to prospect for such blind veins along the tunnel's course and to locate 1500 feet in length upon any such vein that is cut or discovered in the tunnel.

In general, there are no hard and fast forms that must be used in locating claims and a location notice written in pencil will be as valid as any other, if the essential requirements are met. Examples of forms are shown herein for all four classes of claims mentioned above, and these may be safely followed. A valid mining location can be made upon a Sunday or holiday. Witnesses are not required, although of course there are occasions when it may be desirable to have them.

CONFLICTING LOCATIONS

The principle which governs the conflicting claims of appropriators of mining claims and other rights on the public domain is that, other things being equal, the prior locator prevails. A location made within the limits of ground already appropriated is void from the beginning; but the boundary marks of lode locations may be placed upon or across the surface of a prior location, or intervening ground whether patented or unpatented as mining or agricultural ground, for the purpose of securing an extralateral right; but no right is given to the ground within the overlap. If a locator should happen by mistake to place some of the monuments necessary to mark out his boundaries upon another's claim, the location is valid so far as that portion of the ground which was open to locatic

GOOD FAITH

Good faith, as an element in the initiation of mining rights under federal and state laws, is absolutely essential to the validity of such rights, may not be dispensed with, and lack of it vitiates any attempt to initiate such rights.

VOID LOCATIONS

Some instances of void locations are these: A location based upon a discovery which is within the boundaries of a prior claim; when located upon the dip of the vein or lode; a lode location of a placer deposit, or vice versa; a placer location intended to secure a known vein therein; to secure the timber growing thereon; a provisional location; a location or relocation based upon a breach of trust, or based upon trespass; a location without discovery where no attempt is made to discover the same; a discovery without boundaries; or, failure or neglect to comply with the local law in making the location on the ground.

ESSENTIAL ELEMENTS IN LOCATING MINING CLAIMS

The essential elements in locating either lode or placer claims are: discovery of mineral, marking the boundaries, posting the notice of location and the recording of an exact copy of same. The location notice *must* contain the following: (1) date; (2) name of locator or locators; (3) name of the claim; (4) the number of linear feet claimed in length

along the course of the vein, each way from the point of discovery (in the case of a lode location) or the number of feet or acreage claimed (in the case of a placer claim); and (5) distance and direction as nearly as practicable from the discovery point to some permanent, well-known point, natural object or monument such as the confluence of streams, a bridge, hill or road intersection, except in the case of a placer claim located and described in the notice by legal subdivisions, where no other tie-in is needed. The location notice should be posted at the discovery point and it is customary to protect it from the elements in a box, tin can or cairn in plain view.

FEDERAL STATUTES ON MINING LOCATIONS

Title XXXII, Chapter VI, Revised Statutes of the United States, Sections 2318, 2319, 2320, 2321, 2322, 2323, and 2324 are the basic provisions under which all rights to mineral deposits in vacant United States land may be acquired in ''public land states'' such as California. No state law nor local custom of miners may give more than is allowed under federal statute; but such local laws may, and often have, limited these rights by prescribing the number or size of claims, or by placing added burdens upon locators. The above listed sections of the federal statutes are here given verbatim.

Sec. 2318. In all cases lands valuable for minerals shall be reserved from sale, except as otherwise expressly directed by law.

Sec. 2319. All valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, are hereby declared to be free and open to exploration and purchase, and the lands in which they are found to occupation and purchase, by citizens of the United States and those who have declared their intention to become such, under regulations prescribed by law, and according to the local customs or rules of miners in the several mining districts, so far as the same are applicable and not inconsistent with the laws of the United States.

Sec. 2320. Mining claims upon veins or lodes of quartz or other rock in place bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposits, heretofore located, shall be governed as to length along the vein or lode by the customs, regulations, and laws in force at the date of their location. A mining claim located after the tenth day of May, eighteen hundred and seventy-two, whether located by one or more persons, may equal, but shall not exceed, one thousand five hundred feet in length along the vein or lode; but no location of a mining claim shall be made until the discovery of the vein or lode within the limits of the claim located. No claim shall extend more than three hundred feet on each side of the middle of the vein at the surface, nor shall any claim be limited by any mining regulation to less than twenty-five feet on each side of the middle of the vein at the surface, except where adverse rights existing on the tenth day of May, eighteen hundred and seventy-two, render such limitation necessary. The end lines of each claim shall be parallel to each other.

Sec. 2321. Proof of citizenship under this chapter, may consist, in the case of an individual, of his own affidavit thereof; in the case of an association of persons unincorporated, of the affidavit of their authorized

agent, made on his own knowledge or upon information and belief; and in the case of a corporation organized under the laws of the United States, or of any state or territory thereof, by the filing of a certified copy of their charter or certificate of incorporation.

Sec. 2322. The locators of all mining locations heretofore made or which shall hereafter be made, on any mineral vein, lode, or ledge, situated on the public domain, their heirs and assigns, where no adverse claims exist on the tenth day of May, eighteen hundred and seventy-two, so long as they comply with the laws of the United States, and with state, territorial and local regulations not in conflict with the laws of the United States governing their possessory title, shall have the exclusive right of possession and enjoyment of all the surface included within the lines of their locations, and of all veins, lodes, and ledges throughout their entire depth, the top or apex of which lies inside of such surface lines extended downward vertically, although such veins, lodes, or ledges may so far depart from a perpendicular in their course downward as to extend outside the vertical side lines of such surface locations. But their right of possession to such outside parts of such veins or ledges shall be confined to such portions thereof as lie between vertical planes drawn downward as above described, through the end lines of their locations, so continued in their own direction that such planes will intersect such exterior parts of such veins or ledges. And nothing in this section shall authorize the locator or possessor of a vein or lode which extends in its downward course beyond the vertical lines of his claim to enter upon the surface of a claim owned or possessed by another.

Sec. 2323. Where a tunnel is run for the development of a vein or lode, or for the discovery of mines, the owners of such tunnel shall have the right of possession of all veins or lodes within three thousand feet from the face of such tunnel on the line thereof, not previously known to exist, discovered in such tunnel, to the same extent as if discovered from the surface; and locations on the line of such tunnel of veins or lodes not appearing on the surface, made by other parties after the commencement of the tunnel, and while the same is being prosecuted with reasonable diligence, shall be invalid, but failure to prosecute the work on the tunnel for six months shall be considered as an abandonment of the right to all undiscovered veins on the line of such tunnel.

Sec. 2324. The miners of each mining district may make regulations not in conflict with the laws of the United States, or with the laws of the state or territory in which the district is situated, governing the location, manner of recording, amount of work necessary to hold possession of a mining claim, subject to the following requirements: The location must be distinctly marked on the ground so that its boundaries can be readily traced. All records of mining claims hereafter made shall contain the name or names of the locators, the date of the location, and such a description of the claim or claims located by reference to some natural object or permanent monument as will identify the claim. On each claim located after the tenth day of May, eighteen hundred and seventy-two, and until a patent has been issued therefor, not less than one hundred dollars' worth of labor shall be performed or improvements made during each year. On all claims located prior to the tenth day of May, eighteen hundred and seventy-two, ten dollars'

worth of labor shall be performed or improvements made by the tenth day of June, eighteen hundred and seventy-four, and each year thereafter, for each one hundred feet in length along the vein until a patent has been issued therefor; but where such claims are held in common, such expenditure may be made upon any one claim; and upon a failure to comply with these conditions the claim or mine upon which such failure occurred shall be open to relocation in the same manner as if no location of the same had ever been made, provided that the original locators, their heirs, assigns, or legal representatives, have not resumed work upon the claim after failure and before such location. Upon the failure of any one of several co-owners to contribute his proportion of the expenditures required hereby, the co-owners who have performed the labor or made the improvements may, at the expiration of the year, give such delinquent co-owner personal notice in writing or notice by publication in the newspaper published nearest the claim for at least once a week for ninety days, and if at the expiration of ninety days after such notice in writing or by publication such delinquent should fail or refuse to contribute his proportion of the expenditure required by this section his interest in the claim shall become the property of his co-owners who have made the required expenditures.

CALIFORNIA STATUTES GOVERNING LOCATION OF MINING CLAIMS

The federal statutes outline in a general way the methods to be followed in locating claims, but the state statutes, which have grown out of the miners' customs and district rules which in many cases antedated the federal law, go into details about the requirements. The sections of the Public Resources Code of California quoted below give in full detail the requirements for making valid locations in this state.

Public Resources Code, California[2]

Sec. 2301. Contents and Posting of Lode Location Notice

Any person, a citizen of the United States, or who has declared his intention to become a citizen, who discovers a vein or lode of quartz, or other rock in place, bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposit, may locate a claim upon such vein or lode, by defining the boundaries of the claim, in the manner hereinafter described, and by posting a notice of such location, at the point of discovery. The notice shall contain:

(a) The name of the lode or claim.

(b) The name of the locator or locators.

(c) The number of linear feet claimed in length along the course of the vein, each way from the point of discovery, with the width on each side of the center of the claim, and the general course of the vein or lode, as near as may be.

(d) The date of location.

(e) Such a description of the claim by reference to some natural object, or permanent monument, as will identify the claim located.

(The first paragraph is a rather loosely worded and incomplete repetition of Sections 2319 and 2320 of the Revised Statutes of the United States, quoted above. The balance specifically sets forth the five essential items needed to make a valid location notice, and should be carefully followed.)

[2] Parts in italics and within parentheses are reviser's comment, not part of law.

Sec. 2302. Defining Boundaries, Marking Corners

The locator or locators of any lode mining claim shall define the boundaries of the claim so that they may be readily traced, but in no case shall the claim extend more than 1,500 feet along the course of the vein or lode, nor more than 300 feet on either side thereof as measured from the center line of the vein at the surface. Within 60 days after the date of location of any lode mining claim hereafter located, the locator or locators shall erect at each corner of the claim and at the center of each end line, or the nearest accessible points thereto, a post not less than four inches in diameter, or a stone monument at least 18 inches high.

Sec. 2303. Manner of Locating, Marking or Describing Placer Mining Claims

The location of a placer claim shall be made in the following manner:

(a) By posting thereon, upon a tree, rock in place, stone, post, or monument, a notice of location, containing the name of the claim, name of the locator or locators, date of location, number of feet or acreage claimed, and such a description of the claim by reference to some natural object or permanent monument as will identify the claim located.

(b) By marking the boundaries so that they may be readily traced.

Where the United States survey has been extended over the land embraced in the location, however, the claim may be taken by legal subdivisions and no other reference than those of such survey shall be required, and the boundaries of a claim so located and described need not be staked or monumented. The description by legal subdivisions shall be deemed the equivalent of marking.

(This section supplies details which are lacking in the federal statutes for this type of location. It does not, however, specify an exact way of marking a placer claim, as is done for quartz claims. When possible, placer claims should be located by legal subdivisions, as the land office will in practically every case require such conformity with public survey lines before issuing patent. Expense and delay will be saved by locating in this way.)

Sec. 2304. Discovery Work on Mining Claims

(a) Within 90 days after the date of location of any lode mining or placer claim hereafter located, the locator or locators thereof shall sink a discovery shaft upon the claim to a depth of at least 10 feet from the lowest part of the rim of the shaft at the surface, or shall drive a tunnel, adit, or open cut upon the claim to at least 10 feet below the surface.

(b) In lieu of the discovery work required by paragraph (a) of this section, the locator of a placer mining claim may, within 90 days of the date of location, excavate an open cut upon the claim, removing from the cut not less than seven cubic yards of material.

(This provision was intended to curb a heretofore prevalent abuse of the liberal federal statute which allowed holding a mining claim for a maximum period of nearly two years without doing any work. The original requirement as made effective in September 1935, called for enough work to expose the deposit upon which discovery and location was based. In the case of placer locations on buried ancient channels so common in California, it would usually be impossible for the average locator to do this within 90 days. The statute was accordingly amended to the present form in 1939.)

Sec. 2305. Discovery Work on Association Placer Claims

Within 90 days after the date of location of any placer mining claim hereafter located containing more than 20 acres, the locator or locators thereof shall perform at least one dollar's ($1) worth of work for each acre included in the claim. This work may all be done at one place on the claim if so desired, and shall be actual mining development work exclusive of cabins, buildings, or other surface structures. Nothing in this section shall be construed as a modification of the requirements of Section 2304 of this code.

Sec. 2306. Relocations—Discovery Work on Same

The relocation of any lode or placer mining location which is subject to relocation shall be made as an original location is required to be made, except that the relocator may either sink a new shaft upon the ground relocated to the depth of at least 10 feet from the lowest part of the rim of the shaft at the surface, or drive a new tunnel, adit, or open cut upon the ground to at least 10 feet below the surface; or the relocator may sink the original discovery shaft 10 feet deeper than it is at the time of relocation, or drive the original tunnel, adit, or open cut upon the claim 10 feet further or, in the case of placer mining claims, relocator may either excavate a new open cut upon the claim, removing from the cut not less than seven cubic yards of material, or remove from the original open cut not less than seven additional cubic yards of material.

Sec. 2306.5. Perfecting Certain Placer Claim Locations

(This provision allowed a period of 90 days, beginning September 19, 1939, to complete discovery work as required in the amended law Sec. 2304 (b) on those placer claims where literal compliance with the previous requirement had not been feasible.)

Sec. 2307. Penalty for Non-Compliance with Code

The failure or neglect of the locator or locators to comply with the requirements of Sections 2301, 2302, 2304, 2305 or 2306 of this code shall render the location null and void (and no portion of the area within the location shall be subject to relocation by the same locator or locators within the period of three years from the date of the void location).[3]

(The penalty imposed hereunder should not be confused with that resulting from the failure to perform annual assessment work, as covered in Sec. 2321. Under Sec. 2307, the failure to comply with any of the provisions of the state code may result in the claim becoming open to relocation by others in 90 days or less after the date of original location.)

Sec. 2308. Location of Tunnel Right

The locator of a tunnel right or location, shall locate his tunnel right or location by posting a notice of location at the face or point of commencement of the tunnel, which notice shall contain:

(a) The name of the locator or locators.
(b) The date of the location.
(c) The proposed course or direction of the tunnel.
(d) Such a description of the tunnel by reference to some natural object or permanent monument as will identify the claim or tunnel right.

(This section gives the modus operandi for exercising the right given in Section 2323, Revised Statutes of the United States. Refer also to the suggested location form herein.)

[3] See *Judson* v. *Herrington,* 71 A.C.A. 759, which declares the 3-year prohibition to be in conflict with the federal law. Reprinted in California Div. Mines Rept. 42, pp. 57-60, 1946.

Sec. 2309. Marking Boundary Lines of Tunnel Location

The boundary lines of the tunnel shall be established by stakes or monuments placed along the lines at an interval of not more than 600 feet from the face or point of commencement of the tunnel to the terminus of 3,000 feet therefrom.

Sec. 2310. Amended Location Notice

If at any time the locator of any mining claim, or his assigns, apprehends that his original location notice was defective, erroneous, or that the requirements of the law had not been complied with before filing, or in case the original notice was made prior to the passage of this chapter, and he is desirous of securing the benefit of this chapter, such locator, or his assigns, may file an amended notice, subject to the provisions of this chapter, if such amended location notice does not interfere with the existing rights of others at the time of posting and filing the amended location notice. No amended location notice or the record thereof shall preclude the claimant or claimants from proving any such title as he or they may have held under previous locations.

Sec. 2311. Survey Notes and Certificate Part of Record

Where a locator, or his assigns, has the boundaries and corners of his claim established by a United States deputy mineral surveyor, or a licensed surveyor of this state, and his claim connected with the corner of the public or minor surveys of an established initial point, and incorporates into the record of the claim the field notes of such survey, and attaches to and files with such location notice a certificate of the surveyor setting forth (a) that the survey was actually made by him, giving the date thereof, (b) the name of the claim surveyed and the location thereof, and (c) that the description incorporated in the declaratory statement is sufficient to identify the claim, such survey and certificate becomes a part of the record, and such record is prima facie evidence of the facts therein contained.

Sec. 2312. Mill Site Locations

The proprietor of a vein or lode claim or mine, or the owner of a quartz mill or reduction works, or any person qualified by the laws of the United States may locate not more than five acres of nonmineral land as a mill site. The location shall be made in the same manner as required for locating placer claims.

(See also suggested form for location included herewith.)

(A mill site usually adjoins the exterior lines of a lode claim which it serves, but need not necessarily do so, so long as it is used in good faith for mining or milling purposes in connection with the operation of a lode or quartz mine; but if for mining purposes, these must be auxiliary to, and not actually the extraction of, mineral.)

Sec. 2313. Recording Copy of Location Notice

Within 90 days after the posting of his notice of location upon a lode mining claim, placer claim, tunnel right or location, or mill site claim or location, the locator shall record a true copy of the notice together with a statement of the markings of the boundaries as required in this chapter, and of the performance of the required discovery work, in the office of

the county recorder of the county in which such claim is situated. The county recorder shall receive a fee of one dollar ($1) for this service.

(There are now available printed location notice forms which include the form of notice showing performance of discovery work, and these are convenient. If not available, the forms given herein may be copied and attached to the location notice before having it recorded.)

Sec. 2314. Annual Work Required

The amount of work done or improvements made during each year to hold possession of a mining claim shall be that prescribed by the laws of the United States, to wit: One hundred dollars ($100) annually.

Sec. 2315. Affidavit of Annual Labor

Whenever a mine owner has performed the labor and made the improvements required by law upon any mining claim, the person in whose behalf such labor was performed or improvements made, or some one in his behalf shall, within 30 days after the time limited for performing such labor or making such improvements, make and have recorded by the county recorder, in books kept for that purpose, in the county in which the mining claim is situated, an affidavit setting forth the value of labor or improvements, the name of the claim, and the name of the owner or claimant of the claim at whose expense the labor was performed or the improvements were made. The affidavit, or a copy thereof, duly certified by the county recorder, shall be *prima facie* evidence of the performance of such labor or the making of such improvements, or both.

(When work is required, the time for filing the above affidavit expires at the end of 30 days after noon of July 1.)

Sec. 2316. Recorder's Fee for Recording Affidavit

For recording the affidavit required under Section 2315, the county recorder shall receive a fee of ten cents ($0.10) per folio, twenty cents ($0.20) for endorsement, and ten cents ($0.10) for indexing the name of each claim and each owner.

Sec. 2321. Effect of Failure to Perform Required Work: Suspension of Right of Relocation

The failure or neglect of any locator of a mining claim to perform development work of the character, in the manner, and within the time required by the laws of the United States shall disqualify such locator from relocating the ground embraced in the original location or mining claim or any part thereof under the mining laws, within three years after the date of his original location, and any attempted relocation thereof by any of the original locators shall render such location void. (Enacted 1939.)[4]

Sec. 2322. Admissibility in Evidence of Location Records: Force and Effect

The record of any location of a mining claim, mill site, or tunnel right in the office of the county recorder, as provided in this chapter, shall be received in evidence and have the same force and effect in the courts of the State as the original notice. (Enacted 1939.)

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[4] See *Judson* v. *Herrington*, 71 A.C.A. 759, which declares the 3-year prohibition to be in conflict with the federal law.

Sec. 2323. Rules Governing Admission of Copies of Records

Copies of the records of all instruments required to be recorded by this chapter, duly certified by the recorder in whose custody such records are, may be read in evidence under the same circumstances and rules as are provided by law for using copies of instruments relating to real estate, duly executed or acknowledged or proved and recorded. (Enacted 1939.)

Sec. 2324. Construction of Chapter Provisions

The provisions of this chapter shall not in any manner be construed as affecting or abolishing any mining district or the rules and regulations thereof within the State. (Enacted 1939.)

DISCOVERY

"The term 'discovery' has a technical meaning in mining. It may be defined as knowledge of the presence of the precious metals [or other valuable mineral [5]] within the lines of the location or in such proximity thereto as to justify a reasonable belief in their existence." [6]

The discovery should be actual, but not necessarily of present commercial value; be situate within free territory and within the boundaries of the location, and may be upon or underneath the surface of the ground. The discovery is sufficient if it justifies a person of ordinary prudence in making expenditure of labor and money with reasonable prospect of success in developing a paying mine.

A lode location must be based on a discovery of rock in place bearing mineral, not necessarily in a fissure, nor with well-defined walls, but the location must include the top or apex of a vein or lode.

Only one discovery of a mineral deposit is required within a placer location, whether it be for 20 acres or an association placer of 160 acres.

A discovery can not be bisected by a side or end line to constitute discovery in two independent locations.

No location is complete until a valid discovery has been made.

LOCATORS

A location may be made without regard to the age, sex, residence, or citizenship of the locator. A corporation may locate to the same extent as an individual. There is no limit to the number of independent lode or placer locations which may be made by either a natural or artificial person, but each location must be based upon discovery therein. A dummy locator is one who joins in the location of an association placer mining claim in the interest of another person or of a corporation for the purpose of permitting such person or corporation to acquire more land than is allowed him or it by law. Such a location contemplates a fraud upon the government and is good only, say, as to 20 acres, but such a location can possibly only be attacked where the government is either actually or constructively a party as in an adverse suit.

Association locators not implicated in such fraud may select and hold their proportionate share of the location—that is, 20 acres each. An association placer mining location is not invalidated by an agreement made after the location and discovery of mineral, giving one person or a corporation an interest in excess of 20 acres.

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[5] Words in brackets added by reviser.

[6] A. H. Ricketts, American mining law: California Div. Mines Bull. 123, p. 346, 1943.

The right to locate a mill site is limited to the proprietor of a noncontiguous vein or lode claim, or the owner of a quartz mill or reduction works, not owning a mine in connection therewith.

A location made by an alien is not void but is voidable.

Colocators are tenants in common; they are not mining partners unless they unite in working the claim.

Subsequent locators, having knowledge of the previous location, can not avail themselves of defects in the prior and subsisting location.

BOUNDARIES

The location must be distinctly marked upon the ground so that its boundaries can be readily traced. These marks may be placed upon or off the claim or be put upon adjoining patented or unpatented ground but with no right to the ground within the overlap. The boundaries of unpatented claims may be shifted or the location floated, provided, the rights of others are not affected thereby.

The federal law (see Sec. 2324 Revised Statutes of U. S. cited above) is silent as to the kind or position of boundary marks, but these details are supplied in part by the state statute (Chap. 4, Secs. 2302, 2303, Public Resources Code, cited above). For lode claims, there shall be erected "at each corner of the claim and at the center of each end-line, or the nearest accessible points thereto, a post not less than 4 inches in diameter or a stone monument at least 18 inches high."

The state law is no more specific than the federal regarding the marking of the boundaries of a placer claim not located by legal subdivisions, beyond saying they shall be marked so that they may be readily traced. This law exempts the locator from the necessity of marking the boundaries of placer claims which have been located and described by legal subdivisions. Prudence will dictate care however, in taking advantage of this, as there is often great difficulty in actually finding and proving the identity of old section corners and quarter-section corners.

TYING THE CLAIM

It is essential that the posted notice and the record of the location contain a description of the claim located by reference to some natural object or permanent monument as will identify the claim. Speaking generally, any object or monument that will serve to identify the location will be sufficient, but the locator should select the most prominent object or monument possible under the circumstances. Stakes driven into the ground are the most certain means of identification of mining claims when there are no permanent monuments or natural objects other than rocks or neighboring hills. The reference to such monuments or objects required by the mining law applies only when such reference can be made.

The reference made by the locator to the tie line is not, and is not intended to be, as accurate and correct as if made by a competent surveyor, but it should identify the location with reasonable certainty.

PLACER LOCATIONS

The maximum size of a placer location is 20 acres for an individual and 160 acres for an association of not less than eight persons, or if the association is composed of a less number, 20 acres for each individual therein.

A placer claim upon surveyed or unsurveyed public land must be located upon the ground in such shape and position as to conform as nearly as reasonably practicable to the lines of the public survey.

This means that if the location is laid upon unsurveyed lands such location, if reasonably practicable, should have east-and-west and north-and-south bounding lines, should be rectangular, if practicable, and in compact form.

When the placer deposit lies within a canyon, gulch, or an unnavigable stream, the placer location may exclude land not useful for mining purposes if conformity of location with subdivisional lines is unreasonable.

Because of the recent (1935 and 1939) state legislation affecting placer locations, it now is necessary that certain additional location acts be performed. (See California Statutes cited above.)

Tailings deposited upon public land initiate no right to dump thereon; but such land may be located as a placer mining claim by the producer or another or by the producer as a mill site, for dumping purposes, or it may be "scripped." If the tailings are allowed to flow upon the land of another, he is entitled to them. If the tailings are deposited so as to injure the land of another, without his consent, the latter may recover damages or injunctive relief may be granted.

The smallest legal subdivision recognized and provided for by the federal mining law is 10 acres, which must be square in form.

Within 90 days after the posting of the notice of location, a true copy thereof should be recorded in the office of the local county recorder.

Form of Placer Location Notice (on Surveyed Land)

Notice is hereby given that the undersigned has this ______ day of ______, 19__, located a placer mining claim situate on public surveyed land in ______ Mining District, County of ______, State of California, described as follows: The ______ of section ______, in township ______, range ______, M. D. M., containing ______ acres.

This claim shall be known as the ______ placer mining claim.

______, Locator.

Note: (*No witnesses required.*)

Form of Placer Location Notice (on Unsurveyed Land)

Notice is hereby given that I, ______, have this ______ day of ______, 19__, located on public unsurveyed lands in the ______ Mining District, County of______, State of California, a placer claim described as follows: Beginning at a (tree, rock in place, stone, post or monument) upon which is posted the notice of location, running thence (north) six hundred and sixty feet to a post marked ______, thence (east) thirteen hundred and twenty feet to a post marked ______, thence (south) six hundred and sixty feet to a post marked ______, thence (west) thirteen hundred and twenty feet to place of beginning; containing twenty acres.

All of said posts are at least four inches in diameter and set at least one foot in the ground and surrounded by a mound of stone.

This location is situated about (feet) distant from (name some natural object or permanent monument).

The name of this claim is ______.

______, Locator.

Note: (*No witnesses required.*)

In some cases, printed location notice forms may be purchased which carry the necessary form to be filled out, showing the performance of discovery work required under state law, (Secs. 2304, 2305, cited above).

If these are not available, the following form may be used and attached to the location notice before it is recorded.

To be attached to *PLACER* LOCATION NOTICE when recorded:

NOTICE IS HEREBY GIVEN by the undersigned Locator__ of the within described Placer Mining Claim, in accordance with the provisions of Chapter 644 of the Statutes of 1941, which amends Section 2313 of the Public Resources Code of the State of California relating to mining claims:

That there has been sunk a discovery shaft upon said claim at least ten (10) feet deep measured from the lowest point of the rim ____________ (Yes or No); a tunnel ____________ (Yes or No); adit ____________ (Yes or No) upon said claim to at least ten (10) feet below the surface, or an open cut ____________ (Yes or No) from which cut there has been removed not less than seven (7) cubic yards of material.

That the discovery work indicated above has been completed within ninety (90) days from the date of location of said claim.

Dated ________________________ 19____. Locator ______________________

____

____

Note: Mark one of the above to indicate how discovery work was done. This may be NEW work or extension of OLD shaft, adit, tunnel or open cut.
A location of either Lode or Placer mining claim is null and void unless such DISCOVERY work is duly performed and a true copy of Location Notice recorded within ninety (90) days from date of location.
Annual ASSESSMENT work must also be performed within one year after the following first day of July from date of location.

The above form of statement has been suggested as meeting the requirements of Chapter 644 of the Statutes of 1941 which amends Section 2313 of the Public Resources Code, relative to the recording of mining location notices.

LODE LOCATIONS

Theoretically, a lode location should be in the form of a parallelogram, having side lines 1500 feet along the course or strike of the vein or lode running 300 feet on each side of the middle of the vein or lode at the surface, and with parellel end lines. But a lode location of less size and of different or any shape is valid; for instance, it may be in the form of a horseshoe or of an isosceles triangle; but such locations carry no extralateral rights. The side lines need not be equidistant from the middle of the vein at the surface and the end lines need not be straight nor of equal length; but its end lines must be parallel with each other or the location carries no extralateral right. If the side lines be across, instead of along the vein, they become the end lines and the location end lines become the side lines of the location as laid upon the ground; and the extralateral right is diminished accordingly. The presumption is that a lode extends to the entire length of the location, but nonmineral land within a placer location may be eliminated by the land department. A valid lode location includes the exclusive right of possession and enjoyment of the surface within its lines and of all veins or lodes having a top or apex within its lines. A location upon the dip of a vein or lode is invalid.

To make the location valid there must be a strict compliance with the local law providing for the manner of locating lode claims, including the

new statutory requirement covering discovery work and marking of boundaries. (See Secs. 2301, 2302, 2304, 2306, 2307 Public Resources Code of California.)

Form of Lode Location Notice

Notice is hereby given that I, ------, do hereby locate and claim (*fifteen*) hundred linear feet of this vein or lode, together with surface ground extending (*three*) hundred feet in width on each side of the middle of said vein or lode and described as follows: Commencing at a post (*or stone monument*) where this notice is posted, which post (*or stone monument*) is at the point of discovery on said vein or lode and on the center line of this location, I hereby claim (*six*) hundred feet extending in a (*southwesterly*) direction along the course of said vein and (*nine*) hundred feet in a (*northeasterly*) direction. The general course of the vein or lode is (*northeasterly*) and (*southwesterly*) as near as can be determined from present developments. The discovery post (*or stone monument*) is situated about ------------ feet from (*name some natural object or permanent monument and give direction*).

The name of this claim is ------ and it is situated in ------ Mining District, County of ------, State of California.

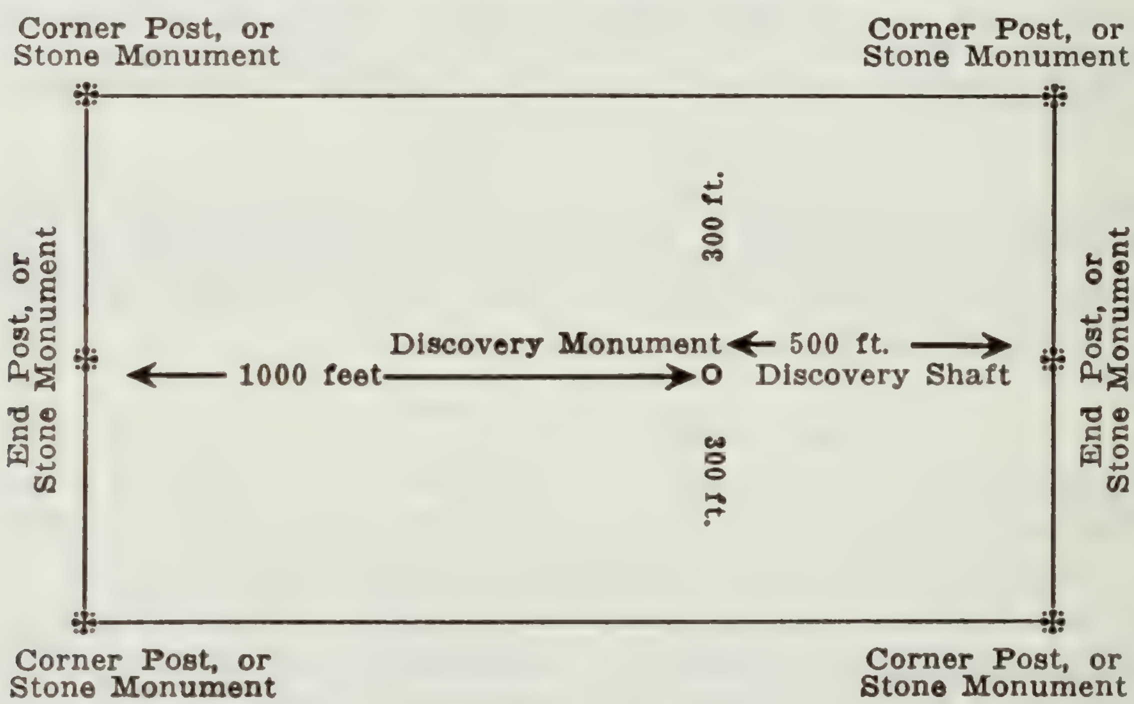
------, Locator.

Date ------------.

Note: (*No witnesses required.*)

(***The post must be not less than four inches in diameter and the stone monument must be at least eighteen inches high.***)

This diagram is intended to give a general ideal plan of location.



The state law now requires that the location notice shall contain a statement that the boundaries have been marked and discovery work has been done as specified in the statute.

The following form is suggested and may be filled out and attached to the location notice unless printed location blanks provide for these statements.

NOTICE IS HEREBY GIVEN by the undersigned Locator__ of the within described Lode Mining Claim, in accordance with the provisions of Chapter 644 of the Statutes of 1941 which amends Section 2313 of the Public Resources Code of the State of California relating to mining claims, that there has been erected at the discovery point, at each corner and at the center of each end line of the said claim, a post not less than four (4) inches in diameter or a stone monument, at least eighteen (18) inches high.

That there has been sunk a discovery shaft upon said claim at least ten (10) feet deep measured from the lowest point of the rim ------------ (Yes or No); a tunnel ------------ (Yes or No);

adit ____________ ; open cut ____________ ; upon said claim to at least ten (10) feet
(Yes or No) (Yes or No)
below the surface.

That the discovery work indicated above has been completed within ninety (90) days from the date of location of said claim.

Dated ______________________, 19____. Locator ______________________

____

____

Note: Mark one of the above to indicate how discovery work was done. This may be NEW work or extension of OLD shaft, adit, tunnel or open cut.

A location of either Lode or Placer mining claim is null and void unless such DISCOVERY work is duly performed and a true copy of Location Notice recorded within ninety (90) days from date of location.

Annual ASSESSMENT work must also be performed within one year after the following first day of July from date of location.

TUNNEL-SITE LOCATIONS

In California the state law prescribes the manner of locating a tunnel site.

A discovery of mineral is not essential to create a tunnel right nor to maintain possession thereof. A failure to work the tunnel site for 6 months is considered an abandonment of the right to all undiscovered veins on the line of the tunnel. The line of the tunnel is the width thereof. The tunnel site must be located upon unappropriated public land and by diligently prosecuting work thereon its claimant has the right of possession of all veins or lodes within 3000 feet from its face on the line thereof, not previously known to exist, discovered in such tunnel, the same as if discovered from the surface. When the discovery is made the tunnel site owner is called upon to make a location on the surface of the ground containing the vein and thus create a mining claim. Such vein may be located 1500 feet on either side of the tunnel or in such proportion thereof on either side as may be desired. The right to such vein dates by relation back to the time of the location of the tunnel. Surface mining claims located by another person subsequent to the commencement of the construction of the tunnel are taken and held subject to any rights of the tunnel owner thereafter developed. The tunnel site may be utilized for development purposes and the work may be credited as assessment work upon claims which are in fact benefited by it. A tunnel site can not be patented.

Form of Tunnel Site Location Notice

Notice is hereby given that I, ______, have this ______ day of ______, 19__, located a tunnel site to be known as the ______ tunnel claim, situate in ______ Mining District, County of ______, State of California, and described as follows: Commencing at this notice of location which is posted at the face or point of commencement of this tunnel and situate about ______ feet from a (*blazed tree*) ______ inches in diameter, marked ______ (*or some other natural object or permanent monument*). The boundary lines of said tunnel site are marked by (*stakes or monuments*) placed along said lines at an interval of not more than six hundred feet from the face or point of commencement of the tunnel to the terminus of three thousand feet therefrom.

______, Locator.

Note: (*No witnesses required.*)

MILL-SITE LOCATIONS

The proprietor of a vein or lode claim or the owner of a quartz mill or reduction works may locate not more than 5 acres of nonmineral land not adjacent to a lode as a mill site in the same manner

as the state law provides for the locating of placer claims. There is no certain form required for a mill site, but it may be noted here that 726 feet by 300 feet contains 5 acres.

A separate mill site is not, necessarily, complemental to each lode location. If the lode location is forfeited or abandoned, the right to the mill site is lost. There is no specific time within which a mill site shall commence to be used as such but the land must be used in good faith in connection with the ostensible purpose for which it was located. It may be located for dumping purposes. It may be located within a forest reserve but not within the limits of a railroad grant. Subsequent mineral discovery within the mill site does not affect the title thereto.

No annual expenditure is necessary on a mill site nor is any statutory expenditure required thereon when patent is applied for in conjunction with a lode claim, as the expenditure on such claim is sufficient.

Form of Mill Site Location Notice

Notice is hereby given that I, ______, proprietor of that certain vein or lode claim known as the ______ mining claim (*or the owner of that certain quartz mill or reduction works known as the* ________) have this ______ day of ________, 19__, located five acres of nonmineral land to be known as the ______ mill site, situate in ______ Mining District, County of ______, State of California, and described as follows: Commencing at a point from which (*name natural object or permanent monument*) bears ______, feet; thence (*south*) seven hundred and twenty-six feet; thence (*west*) three hundred feet; thence (*north*) seven hundred and twenty-six feet; thence (*east*) three hundred feet to the point of beginning.

The name of this mill site is ______.

______, Locator.

Note: (*No witnesses required.*)

TOWNSITES

No title can be acquired under a townsite entry to any vein of gold, silver, cinnabar, copper, or lead, nor to any valid mining claim or possession, held under existing laws.

A valid mining claim, therefore, is not affected where it was known prior to the townsite patent that a mineral vein existed where the discovery was made; that is, land held as a valid and subsisting mining claim at the time of the issuance of the townsite patent, does not pass under such patent, nor is the title or right of possession of the location at all affected thereby.

Mineral land within a patented townsite can not be located.

There is no conflict between a lode or a placer patent and a townsite patent, and there can be none.

A mill site has been held to be a mining claim within the purview of the townsite act.

RELOCATION

A subsequent location of a forfeited or abandoned mining claim is a relocation and not an original nor amended location. It is made in the same manner and is subject to the same conditions as an original location. It is void if it embraces a valid and subsisting claim. A valid relocation on the ground of forfeiture due to failure to perform annual labor can not be made until after the expiration of the assessment year; i.e., after 12 o'clock noon on July 1; but if forfeiture is due to failure to observe state law, relocation may come after 90 days but an abandonment of the claim gives the right of immediate relocation. All improvements which are

attached to or become a part of the realty pass to the relocator. The location rights, however, may be preserved by a resumption of labor in the absence of an intervening right. There can be no provisional relocations; that is to say, the validity of the relocation can not be made to depend on whether or not the mine owner failed to do the annual work subsequently or may abandon his claim. A mining claim is not subject to relocation for failure to perform the assessment work if such work has been resumed after the expiration of the year and before any valid relocation is attempted. A person, holding confidential relations with the owner of a mining claim, for example, a lessee or optionee, who in violation of a contract or in breach of the trust attempts to relocate the claim in his own name, will be held as a trustee for the rightful owner and he will secure no advantage by such act. A relocation by a cotenant inures to the benefit of his cotenants and he can not by recording in his own name prejudice their rights nor forfeit his own undivided interest thereby. A relocator or other person may attack the verity of the recorded affidavit of labor and show its falsity. (See Sec. 2306, Public Resources Code of California.)

AMENDMENT OF LOCATION OR RECORD

The office of an amended location is to cure defects or supply omissions in the original location or in the posted notice or the record. It may serve to change the boundaries or the name of the claim or add the names of additional locators. It may include additional territory if without prejudice to the rights of others. It does not require additional discovery in the added ground, physical possession nor additional expenditure. It works no forfeiture of previously acquired rights not inconsistent with the amendment. It relates back to the date of the original notice where no adverse rights have intervened. It must be based upon a preexisting but not necessarily perfect location. It can not be made to exclude the name of a colocator without his knowledge and consent. It can not be made by a person who has parted with his title. There is no limit as to the time within which it may be posted or recorded.

Form of Amended Location Notice

Know all men by these presents, that ______, the undersigned, has this ______ day of ______, 19__, amended, located, and claimed and by these presents does amend, locate, and claim by right of discovery and amended location in compliance with section 2310 of the Public Resources Code of California (*fifteen*) hundred linear feet of the ______ lode, vein, ledge, or deposit along the vein together with (*three*) hundred feet on each side of the middle of the said vein at the surface situate in ______ Mining District, County of ______, State of California, and described as follows: Beginning at corner No. 1, whence (*name some natural object or permanent monument*) is distant ______ feet in a ______ direction, thence (*northeasterly*) (*fifteen*) hundred feet to corner No. 2, thence (*southeasterly*) (*three*) hundred feet to end center monument, thence (*southeasterly*) (*three*) hundred feet to corner No. 3, thence (*southwesterly*) (*fifteen*) hundred feet to corner No. 4, thence (*northwesterly*) (*three*) hundred feet to end center monument, thence (*northwesterly*) (*three*) hundred feet to point of beginning. This being the same lode originally located on the ______ day of ______, ____, and recorded on the ______ day of ______, ______, in Book ______, page ______ of ______ records in the office of county recorder of said ______ County. This further and amended notice of location is made without waiver of any previously acquired rights, but for the purpose of correcting any errors or defects or omissions in the original location, description, or record and to secure all the benefits of said section of said Civil Code.

______, Locator.

The statement about discovery work and marking of lode claims should be used.

ANNUAL EXPENDITURE OR ASSESSMENT WORK

Annual expenditure consists of labor done or improvements made upon both lode and placer claims and must be *worth* at least one hundred dollars. It must be done or made before 12 o'clock noon of the first day of July of each year subsequent to the location year until patent or the receiver's final receipt has issued to the mine claimant (unless congress has declared a moratorium for that particular year, which must be consulted as each moratorium may, and usually does, vary in detail or unless the location was made prior to governmental withdrawal or the Leasing Act. Within withdrawn areas neither assessment work nor patent is necessary to preserve the possessary right of the claimant; and he holds his claim in perpetuity unless he loses his rights by abandonment). If not so made, and there is no resumption of labor the claim is subject to adverse relocation.

Assessment work may be done either underground or upon the surface, upon or off the claim itself, if of benefit or value to it. Any work done for the purpose of discovering minerals is "improvements" within the spirit of the statute. Any building, machinery, roadway, or other improvement used in connection with, and essential to the practical development of the claim will enter into and form a part of the expenditure for improvements. Under some circumstances the services of a watchman may be counted as annual expenditure. In determining the amount of work done on a claim for the purpose of representation, the test is as to the reasonable value of said work, not what was paid for it nor what the contract price was, but it depends entirely upon whether or not said work was *worth* the sum of one hundred dollars.

Labor may be done or improvements made upon or at a distance from any one of the locations comprising a group of claims when of benefit and value to the entire group. Any location within the group not so benefited may become subject to forfeiture. The expenditure must equal in the aggregate the amount required on all the locations. The test of sufficiency is whether the expenditure tends to facilitate the development or actually promotes or directly tends to promote the extraction of mineral from or improve the property or be necessary for its care or the protection of the mining works thereon or pertaining thereto.

The amount of the annual expenditure upon a placer claim is the same whether for 20 acres or on an association claim of 160 acres; viz., one hundred dollars.

A certain number of days work at a certain sum a day, or work of a certain character or extent do not constitute the requisite expenditure under the mining laws.

Labor done or improvements made may be sufficient to hold the claim although not in fact paid for or when gratuitously performed; but payment for work not done will not suffice.

The annual expenditure may be made by the locator, his heirs, assigns or legal representatives, or by some one in privity therewith, or by one who has an equitable or beneficial interest. A stockholder in a corporation claiming the property, or a receiver appointed by a court are within the rule; but labor done or improvements made by a trespasser or stranger to the title will not inure to the benefit of the claimant.

Annual expenditure is not required upon a mill site nor upon a tunnel site; but failure to prosecute the work on the tunnel for 6 months

shall be considered as an abandonment of the right to all undiscovered veins on the line of such tunnel. Yet the work on it may count as annual labor on claims which it is so run as to cut and develop; or be applied as patent expenditure.

Wrongful adverse possession of a mining claim excuses the rightful owner or locator from doing the assessment work required by law, during the time of such adverse possession.

Annual assessment work may be applied to patent expenditure.

FORFEITURE OF INTEREST FOR FAILURE TO PAY SHARE OF TAXES

Chapter 1292, Statutes of 1945, effective September 15, 1945, provides that upon the failure of any co-owner of a mine or claim to contribute his proportionate share of the taxes which have been levied and assessed upon the mine or claim for the period of five years, the co-owner or co-owners who have paid such share may at the expiration of the five years serve upon the delinquent co-owner notice thereof. If the delinquent co-owner fails or refuses to contribute his share of such taxes within 90 days after the service of such notice, the co-owner contributing such share may file in the superior court of the county in which the mine is situated, a petition setting forth the facts. After proper notice and hearing, the court may order judgment vesting the interest of the delinquent in the mine or claim in the petitioner.

WAR-TIME EXEMPTIONS FROM ANNUAL LABOR

Public Law No. 861, passed by the 76th Congress and known as the Soldiers' and Sailors' Civil Relief Act of 1940, provides (Sec. 505) that the terms of Sec. 2324 of the Revised Statutes of the United States, requiring annual labor on mining claims, "shall not apply during the period of his service, or until six months after the termination of such service, or during any period of hospitalization, because of wounds or disability incurred in line of duty, to claims or interests in claims which are owned by a person in military service and which have been regularly located and recorded."

In order to obtain the benefits of this section the claimant of such mining location shall, before the expiration of the assessment year during which he enters military service, file or cause to be filed in the office where the location notice or certificate is recorded, a notice that he has entered such service and that he desires to hold his mining claim under this section.

Sec. 506 of the same law permits the suspension of mining operations on United States land held under permit or lease for a similar period and waives payment of rentals or royalties for such period, provided that the permittee or lessee shall within 6 months after the effective date of the act, or 6 months after his entrance into military service notify the General Land Office by registered mail of his entrance into such service and of his desire to avail himself of this section. The above law was approved in time to affect work for the year ended July 1, 1941.

On May 3, 1943 another act of congress was approved which suspended the requirement for annual assessment work on *all* mining claims in the United States including Alaska until noon July 1 following the cessation of hostilities in the war.

In order to benefit by the act, the claim owner must file or cause to be filed, in the office where the location notice or certificate is recorded,

(which in California is the County Recorder's office) on or before 12 o'clock noon July 1 for each year that the act remains in effect, a notice of his desire to hold said claim. Provisions of this act expired on July 1, 1947.

CONTRIBUTION

Persons who acquire undivided interests in a mining claim by location or otherwise are known as cotenants or co-owners, and any one or more who fail to contribute the proportionate share of the assessment expenditure may be "advertised out" by the remaining party or parties. This may be done by personal service, in writing, or by publication in a newspaper published nearest the claim for at least once a week for 90 days and if at the expiration of 90 days after such notice in writing or 180 days from the first day of such publication such delinquent or delinquents should fail or refuse to contribute his proportion of the expenditure required by law, his interest in the claim shall become the property of his co-owners who have made the required expenditures and given said notice. California law provides for the giving of such notice for contribution and the manner of establishing the same of record in the office of the local county recorder, and also of the fact of payment or nonpayment, as the case may be.

PROOF OF ANNUAL LABOR

California mining law provides for the making, recording and legal effect of affidavits of annual expenditure. Within 30 days after the time limited for performing labor or making improvements upon a mining claim—that is, 12 o'clock noon of July 1—the mine owner or some one in his behalf may make and have recorded by the local county recorder an affidavit setting forth the value of the labor and improvements made, the name of the claim or claims, and the name of the owner or claimant of such claim at whose expense the same was made or performed. If this affidavit is filed before or within the said time, it presents prima facie evidence of the facts properly therein stated; but not otherwise. If filed after said 30 days, it has no legal effect. This affidavit does not prevent other proof by the claimant nor attack by his adversary. Neither the failure to record the affidavit nor a mistake therein will work a forfeiture of the location. Its due filing tends to prevent an adverse relocation.

Form of Affidavit of Annual Labor

State of California } ss
County of________ }

______, being first duly sworn, deposes and says, that at least (*one*) hundred dollars worth of labor was performed (*or improvements made*) between 12 o'clock noon of the first day of July, 19__, and 12 o'clock noon of the first day of July, 19__, upon the ______ mining claim situate in the ______ Mining District, County of ______, State of California. Such expenditure was made by or at the expense of ______, the owner of said claim, for the purpose of complying with the federal and Californian mining laws pertaining to annual assessment work.

Subscribed and sworn to before me this ______ day of ______, 19__. ______, Notary Public in and for the County of ______, State of California.

My commission expires ______.

RESUMPTION OF LABOR

A mine claimant who has failed to do the annual labor during the statutory assessment year may resume work at any time thereafter, in the absence of an intervening right.

To "resume work" is to begin work in good faith and diligently prosecute the same to completion before a valid adverse relocation, and thereafter the rights of the mine claimant are precisely what they were before the default.

Work is not resumed by the mere purchase of material or the mere bringing of the same upon the claim.

The Federal Leasing Act of 1920 did not have the effect of extinguishing the right of the locator under the mining act to save his claim under the original location by resuming work at any time after failure to perform the annual assessment labor in the absence of adverse relocation or intervening right.

RELIEF ACT FOR GOLD AND SILVER MINING OPERATORS

The moratorium on the discharge of obligations incurred in connection with the lease, purchase or outfitting for operation of any property which produces no revenue except from the mining of gold and silver, and where the party under obligation has been prevented from discharging the debt by any law, rule, regulation or order of the United States, which became state law in 1943 and would have expired October 1, 1945, was extended by the 1945 session of the legislature. (Chapter 294, Statutes of 1945.)

This moratorium will remain in effect

"until six months after the termination of hostilities between the United States and all nations with which the United States is at war as determined by an act of Congress or proclamation of the President of the United States, or until October 1, 1947, whichever first occurs."

The new statute amends parts of the former act (Chapter 207, Statutes of 1943) and also affects other laws which may apply to court procedure in such cases, so should be consulted by anyone planning to seek relief. These two acts provide for the manner of filing the necessary petition for relief in the superior court of the county in which the mine, machinery or equipment is situated, and specify court procedure.

INDEPENDENT CONTRACTOR

Where the mine owner retains the right to direct the mode and manner in which the assessment work shall be done for an agreed per diem, the relation of master and servant exists and the employer is liable in damages for injuries which may be sustained by his employee while he is engaged in such employment. But, if work is done under a contract, such as to excavate a tunnel of certain dimensions for an agreed number of lineal feet, or to sink a shaft of a certain size to a certain depth, for an agreed amount, and the mine owner has no right of control as to the mode of doing the work contracted for, the party so doing such work is an independent contractor, and he, and not the mine owner, is liable for such injuries.

Form of Contract

The terms of the agreement made this ______ day of ______, 19__, between ______, party of the first part, and ______, party of the second part, are as follows, viz: That the said party of the second part shall excavate or run ______ lineal feet of tunnel work within the ______ mining claim situate in the ______ Mining District, County of ______ and State of California, commencing at a point to wit: ______ feet (*west*) from the (*east end center monument of said claim*) for the agreed sum or price of ______ dollars per lineal foot; said tunnel to be ______ feet in width and ______ feet in height, in the clear, and to be timbered where necessary. Payment

therefor by said party of the first part shall be made in full within ______ days after the full completion of said work. Work upon said tunnel under this contract shall commence within ______ days from the date hereof and the same shall be fully completed in proper and minerlike manner by said party of the second part on or before the thirtieth day of June next thereafter ensuing ; said party of the second part to hold said party of the first part harmless as against all and every lien of laborers, miners, and mechanics, and for materials furnished.

In witness whereof the said parties hereto have hereunto, and to its duplicate, set their hands the day and year first above written.

PATENTS

A patent is not essential to the enjoyment of a mining claim. There is no restriction as to the time when it shall be applied for nor as to its use or sale. It confers no greater mining rights than those obtained by a valid location. It, however, establishes the exterior boundaries of the claim, that discovery has been made, and dispenses with the performance of annual labor. A patent is not always conclusive of the title, as, for one thing, it may, possibly, be shown that the patentee is an undisclosed trustee.

Lode, and placer locations upon unsurveyed lands, must be officially surveyed for patent. No survey is required for placer locations laid in conformity with legal subdivisions.

ADVERSE CLAIMS

When a patent is applied for, the owner of a prior conflicting location must duly institute adverse proceedings; otherwise, he will be treated in law as having voluntarily waived his prior and superior rights, and his adversary will secure a patent covering his location or a part thereof. The adverse must be filed in the local land office within the 60-day publication of the application for patent and followed by suit in a court of competent jurisdiction within 30 days thereafter and be diligently prosecuted to final judgment. No equitable title nor existing lien is disturbed by the issuance of the patent.

PROTESTS

A protest may be filed at any time by any person before patent actually issues. The protest may be directed against the patenting of the claim as applied for upon any ground tending to show that the applicant has failed to comply in any matter essential to a valid entry under the patent proceedings; as for instance, that no mineral has been disclosed within the claim applied for, that the necessary expenditure of five hundred dollars has not been made by the proper party; or it may be filed by a cotenant excluded from the application for patent. A protest never can take the place of an adverse.

TENANCY IN COMMON

A tenancy in common arises from the joint location of or ownership in a mining claim and consists of undivided interests therein. The parties thereto are not mining partners unless they work the mine together by agreement. A cotenant who does not exclude his cotenants, may work the mine in the usual way and extract ore therefrom without being chargeable with waste or liable to the other cotenants for damages, and an injunction will not be granted at their instance to prevent the working of the mine.

The operating cotenant works the property at his own expense; he alone must sustain any loss which results from his working the property and he alone is responsible for the debts thereby contracted; he must account to the nonparticipating cotenants for their pro rata share in the net results.

The title of a cotenant may be divested after due notice, to contribute his proportion of the annual expenditure, or by the actual adverse possession for the statutory period of the other cotenants, or some of them, evidenced by ouster, or by obtaining a patent from the government in their own names unless the excluded cotenant brings suit to enforce the trust when not barred by laches, the statute of limitations or the rights of third parties without notice. Hence, such excluded cotenant need neither file an adverse nor a protest against such application for patent. A cotenant becomes a trustee for his cotenants when he relocates the claim or permits its relocation by a third person with whom he is in collusion, or obtains a patent in his own name.

A cotenant may maintain an action for the recovery of the claim without joining his cotenants. A cotenant may sell or encumber his undivided interest at pleasure but he can not sell, lease, or encumber a specific part of the common land.

See also, *Working the Claim,* below.

MINING PARTNERSHIP

(Chap. 5, Secs. 2351-2360 incl., Public Resources Code of California.)

To constitute a mining partnership, two or more parties must be associated together in the ownership or possession of a mining claim in some way and actually engage in working the same.

The partnership is not dissolved by the death of a partner nor by the sale of a partnership interest. The purchaser, from the date of his purchase, becomes a member of the partnership. The partners are in the relation of trustees for each other. The property worked and the business of the partnership may be controlled by a majority of the members of the partnership acting for the best interest of all concerned. Each partner is jointly liable for the debts of the firm.

As previously suggested, the property worked is not necessarily property owned by the partnership, if it be so, it is subject to the lien of each member of the firm for debt due to himself or to the creditors of the firm. One mining partner may sue his copartner for an accounting. A partner may properly sell his interest at a greater price than that received by the other partners.

GRUBSTAKE CONTRACTS

(Chap. 7, Sec. 2606, Public Resources Code of California.)

A grubstake contract is an agreement, in writing, and recorded in the office of the county recorder of the county in which said instrument is made. It must be duly acknowledged before a notary public or other person competent to take acknowledgment. It is prima facie evidence in all courts of this state in all cases wherein the title to mining locations and other locations under the mining laws of this state are in dispute.

A grubstake, or prospecting contract, as it is sometimes called, is where one of the parties thereto, called the outfitter, is to furnish the other, called the prospector, supplies, money or both, to and while the

other is prospecting for and obtaining mineral land, by location, for their joint advantage or in such proportion as may be agreed upon. It is the duty of the prospector to use reasonable diligence and make reasonable exertions in seeking mineral deposits, and within a reasonable time make proper location covering discovery. It does not constitute a mining partnership unless the parties thereto actually engage in the joint working of the property; otherwise, they are tenants in common.

All locations made during the existence of the contract inure to the benefit of each of the parties thereto, whether made in the name of only one of them, or in the name of a third person, at the instigation of either. Where a prospector conceals locations made in his own name, or for him, individually, he holds the title thus acquired, or the property for which it is exchanged or the price for which it is sold as a trustee in bad faith for the use and benefit of the outfitter, and will be compelled to make restitution.

It is essential to a right in mining property acquired under a grubstake contract that such property should be acquired by means of the grubstake furnished and pursuant to such contract.

The contract must be founded upon an adequate consideration, and be just and reasonable; that is, it must not be a hard bargain on the prospector.

OPTION

An option is a right acquired by contract to accept or reject a present offer within a limited time. It may be coupled with a lease. Time is of the essence of the contract, whether so therein expressed or not. It must be based upon a sufficient consideration; otherwise, it may be withdrawn at any time before acceptance. A consideration of one dollar, in the absence of fraud or bad faith, or the making of expenditures upon the property, as for instance, the performance of the annual assessment work thereon, is a sufficient consideration. After acceptance by the optionee, the parties are mutually bound and the option may be specifically enforced. An option usually is accompanied by the duly executed deed of the optioner, which is placed in escrow to be delivered to the optionee upon his performance of the conditions of the option, or to be returned to the maker in the event of default; in the meantime the title to the property remains in the grantor and subject to claims against him. The deed when delivered will relate back to the date of the escrow agreement and cut off any intervening rights or equities acquired by a third party who had notice of the terms and conditions of the escrow. Hence, the option should be recorded by its holder. At the time the escrow is made, and as a part thereof the option holder properly should execute a quitclaim of the property to the optioner to be delivered to him upon default of the optionee or to the latter upon full compliance with the terms of the option. This is to clear the record title to the property, if there be no conveyance under the terms of the option.

Delivery of the deed by the escrow holder, contrary to instruction, confers no title, particularly as against those who take with notice.

Short Form of Option

In consideration of the sum of ______ dollars, to me in hand paid, I, the undersigned, will sell to ______ my certain mining claim known as ______ situate in ______ Mining District, County of ______ and State of ______ for the sum of ______ dollars, at any time within ______ months from date, payable as follows, to wit: ______.

Upon full payment made I will convey said mining claim to said optionee by a good and sufficient deed.

The right of entry and possession of said premises is hereby given to said optionee together with the right to extract ore therefrom, but with no right thereto or removal thereof, unless and until this option be consummated according to its terms.

All work done upon said mining claim by said optionee shall be done in a minerlike manner and at the sole cost and expense of the optionee. Actual work upon said premises to commence on ______ and to proceed with reasonable diligence unless prevented by strikes, the elements, unavoidable accidents or other causes beyond the control of the optionee.

The optionee shall keep said premises free and clear of all costs, liens and encumbrances done, made or suffered by him—and see that the notice of non-responsibility which may be posted by the optioner upon said premises to protect the same from such liens, is kept in place.

The optionee hereby agrees to carry workmen's compensation insurance in a responsible company, said policy to be placed in force immediately upon the commencement of said work.

The optionee shall and will quietly and peaceably quit and surrender said premises and any ore extracted by him therefrom upon the termination of this option from any legal cause.

Upon the failure to make any payments herein provided for upon said purchase price of said premises at the time herein specified for the same to be made, the right of the optionee shall immediately cease and determine and the payments theretofore made by him shall immediately become the property of the optioner, and the optionee hereby waives all claim thereto.

All machinery and improvements placed upon said premises by the optionee may be removed by him within ______ days after the termination of this option.

Witness my hand this ______ day of ______.

____

LEASES

Each mining lease has its own peculiar details. The form of words used is of no consequence. It is the intention of the parties, as expressed in the instrument, and not its form that determines whether it is a lease or a license or a contract for labor. If the contract gives exclusive possession it is a lease; if it merely confers the privilege of occupation, under the owner, it is a license; if it fixes a rule for compensation for services rendered, as, for instance, a share of the profits realized in working the mine, it is a contract for labor. A lease is sometimes coupled with an option to purchase the property leased, in which case they are separate instruments and the option may outlive the lease. Time is always of the essence of both documents whether so expressly stated or not. Where there is any doubt or uncertainty as to the meaning of covenants in such a lease they are construed strongly against the lessor and in favor of the lessee. A covenant to work the property continuously means continuous to the end of the term. A mere covenant to work the property is not tantamount to a covenant to work continuously. If the payment of royalty is provided for, the lessee is bound to proceed with his mining operations with reasonable diligence. The lease is subject to abandonment or forfeiture. A location may be made and leased on the same day. No lease should be for a longer period than twenty-five years. If it be for a period of one year, or less, it need not be in writing. Where there is no agreement in the

lease against subletting, the lessee has the right to sublease all or portions of the land for the purpose specified in the lease. A stipulation as to the removal of machinery or other improvements placed by the lessee is controlling. The term "gross proceeds" means the entire proceeds of the ore mined, less the cost of sampling, freight, and treatment of the ores.

Short Form of Lease

This agreement of lease made and entered into this ______ day of ______, 19____, by and between ______ and ______ Witnesseth: That the lessor for and in consideration of ______ dollars, cash in hand paid, receipt of which is hereby acknowledged, and of the covenants and agreements hereinafter contained on the part of the lessee to be paid, kept and performed, does grant, convey, demise, and let exclusively unto the said lessee that certain tract of land situate in ______ Mining District, County of ______, State of California, described as follows:

(*Insert description*)

for the sole purpose of exploring, operating and mining precious and other minerals and to sell the products thereof and to pay to the lessee a royalty of ________ percent of the gross proceeds within ten days after each clean up.

The lessee agrees to keep said premises free and clear of all costs, liens and encumbrances done, made or suffered by permit, the lessor to place and maintain in a conspicuous place upon said premises such notice as shall be lawfully necessary to protect the lessor against such claims.

All machinery and improvements placed upon said premises by the lessee may be removed by him within ______ days after the termination of this lease.

The lessee hereby agrees to carry a workmen's compensation policy in a responsible company; said policy to be placed in force upon the commencement of said work.

It is agreed that this lease shall remain in force for a term of ______ years from this date.

Witness our hands the day and year first above written.

Form of Notice of Nonresponsibility for Labor or Materials Furnished

Notice is hereby given to all persons, that the undersigned ______ is the owner of ______ mine (*or mining claims*) hereinafter described, with all the improvements thereon. That said mine (*or mining claims*) now is in the possession of and is being worked and operated by ______, pursuant to a contract (*or option to purchase, or lease*) made and executed by the undersigned in favor of said ______, dated ______ 19____, said contract (*or option to purchase, or lease*) to be in force up to and including ______ 19____.

The undersigned is not working nor operating said mine (*or mining claims*), nor any portion thereof, and does not intend to work or operate said mine (*or mining claims*), nor any part thereof, nor purchase any supplies or materials therefor, during the life of said contract (*or option to purchase, or lease*) with said _____.

The name of said mine (*or mining claims*) is ______ and is situate, lying and being in ______ Mining District, County of ______, State of California. The notice of location of said mine (*or mining claims*) being duly recorded in Book ______, at page ______, of the records of said ______ county in the office of the county recorder of said county to which said record reference is hereby made for a more particular description of said mine (*or mining claims*).

In witness whereof, the said ______ has hereunto set his hand this ______ day of ______, 19____.

State of California }
County of_________ } ss

______, being first duly sworn, according to law, deposes and says: That he is the owner of the premises particularly mentioned and described in the foregoing Notice of Nonresponsibility for Labor or Materials Furnished. That he has read

the same and knows the contents thereof. That the same is true of his own knowledge. Subscribed and sworn to before me this ______ day of ______, 19____.

Notary Public in and for the County of ______,
State of California.

My commission expires ______.

NOTE.—This notice must be posted in a conspicuous place upon the property within ten days after the owner (or person having or claiming interest therein) has obtained knowledge of construction, alteration or repair work or labor upon such property and he should file for record a verified copy of said notice in the office of the proper county recorder. The foregoing verification may be made by any one having knowledge of the facts, on behalf of the owner or person for whose protection the notice is given.

DEEDS

A mining claim can be transferred only by operation of law or by a deed in writing; but a discoverer of mineral may transfer his right of location by parol. A mining claim which has a known descriptive name may be sufficiently described by such name, coupled with a proper reference to the record, or if patented, to the survey number. That a claim is known by several names and only one of them is given in the deed is immaterial. Minerals may be granted without the surface, or vice versa. Where there is a severance, the owner of the mineral has a right to occupy so much of the surface as is reasonably necessary for mining purposes. No attesting witnesses to the execution of a deed are required. If the title to an unpatented claim stands alone in the name of one spouse, it is not essential to the title that the other spouse should join in the execution of the deed.

A quitclaim deed is sufficient to pass the title, if clear.

FORM OF DEED

I, ______, grant (*or quitclaim*) to ______, that certain mining claim situate in the ______ Mining District, County of ______, State of California, and being the ______ mining claim, and more fully described in volume ______, page ______, of the records of (*quartz claims*) records of said county (*or being Mineral Survey No.* ___).

Witness my hand this (*insert day*) of (*insert month*), 19__.

______.

WORKING THE CLAIM

To work a mining claim is to do something toward making it productive, such as developing or extracting an ore body after it is discovered.

A mine owner is entitled to work his mining claim in a lawful manner; but no manner can be considered lawful which precludes another from the enjoyment of his rights, if his work in fact injures the property of another, be he ever so cautious or careful to avoid injurious consequences. (For instance, allowing his tailings to flow upon another's land without his consent.) In such case, the trespasser not only loses his title to the tailings but is liable for damages besides.

The word "shift" means a set of workmen who work in turn with other shifts, as a night shift. It means, also, a day's work.

See also *Tenancy in Common,* above.

PAYMENT OF WAGES

Chapter 628, Article 3, Section 270, Statutes of 1945 (Labor Code) changed slightly the wording of this requirement. It now reads as follows:

"No person, or agent or officer thereof, engaged in the business of extracting or of extracting and refining or reducing minerals other than petroleum, except persons having a free and unencumbered title to the fee of the property being worked and except mining partnerships in respect to the members of the partnership, shall fail or neglect, before commencing work in any period for which a single payment of wages is made, to have on hand or on deposit with a bank or trust company, in the county where such property is located or if there is no bank or trust company in the county, then in the bank or trust company nearest the property, cash or readily salable securities of a market value sufficient to pay the wages of every person employed on the mining property, or in connection therewith, for such period.

Any person, or agent or officer thereof, who violates this section is guilty of a misdemeanor."

See also *Independent Contractor,* above.

FIXTURES

(Chap. 7, Sec. 2601, Public Resources Code of California.)

A fixture is an article which may or may not actually be affixed to the mine. In this state sluice boxes, flumes, hose, pipes, railway tracks, blacksmith shops, mills, and all other machinery or tools used in working, or developing a mine are deemed to be affixed to the mine. See also *Relocation,* above.

LOCATION WORK AND ASSESSMENT WORK DISTINGUISHED

Confusion of thought has arisen among mining locators as to the effect of the provision of the state mining law relating to location or discovery work upon both lode and placer mining claims as affecting the federal requirement of annual assessment work upon such locations. There is no conflict between the two laws nor is the one merged with the other. Hence, a location of either lode or placer is null and void unless such location work is duly performed; and the possessory right to an unpatented location can not be maintained without due performance of the annual assessment work.

In other words, the state statute places an additional burden upon the mining locator, on claims filed on and after September 15, 1935.

USE OF WATER

A landowner (including the owner of a valid, unpatented mining claim) has a riparian right to the use of water which flows across, rises upon or percolates through his land, insofar as this water has not been previously put to beneficial use by legal appropriators or by other riparian owners farther downstream. The landowner can make any reasonable use of such water upon his riparian land, that does not deprive the prior claimant of the quantity and quality of water to which he is entitled. This includes consumptive use of any unclaimed part of the flow. No formality is required for such riparian use.

Where the water does not naturally flow across the land but is brought to it by diversion from an outside point, such appropriation should be made according to state law. This law is administered by the State Division of Water Resources, Department of Public Works, 401 Public Works Building, Sacramento, to whom requests for information and necessary forms should be addressed.

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STATE OF CALIFORNIA
EARL WARREN, GOVERNOR
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO
OLAF P. JENKINS, Chief

Vol. 44 APRIL 1948 No. 2

CALIFORNIA JOURNAL OF MINES AND GEOLOGY

STATE OF CALIFORNIA
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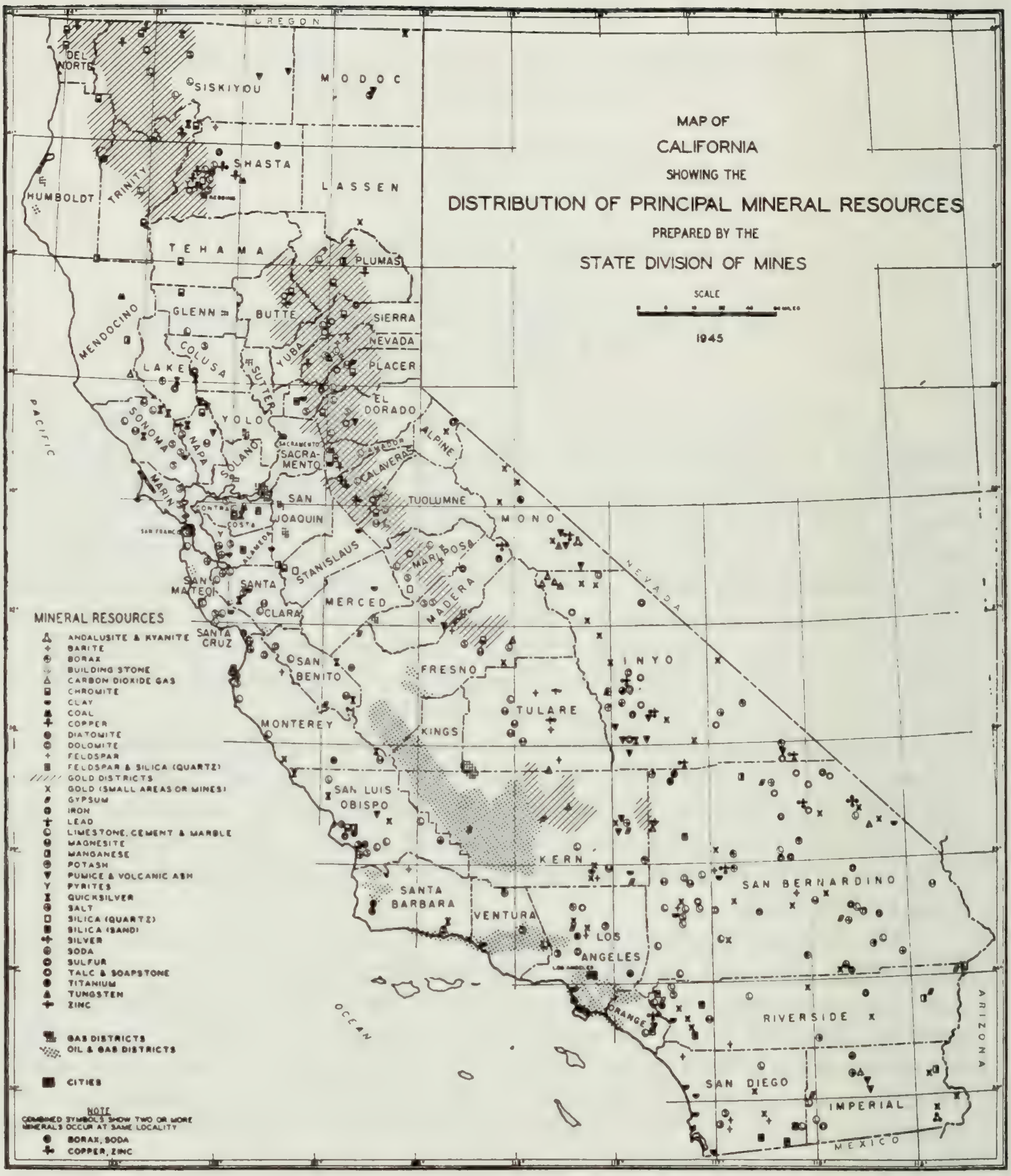
The Division of Mines maintains at its headquarters offices in San Francisco a technical library containing several thousand books and scientific journals on geology, mining, mineralogy, chemistry, metallurgy, and related subjects; a reading room containing periodicals devoted to the petroleum and mining industries, and newspapers from the mining centers of the state; exhibits of minerals, rocks, mine models, etc.; a service laboratory for the determination of California minerals; and a conference room with a mining engineer in attendance to serve the public and to sell publications of the Division. Publications are also sold at the Los Angeles and Sacramento district offices.

In addition to oral conferences in the offices of the Division of Mines, information concerning the mineral resources, mineral industry, geology, and mining operations of California is distributed to the public by means of publications, multigraph releases, and letters. Each letter of inquiry received by the Division is answered by the technical staff member best qualified to do so.

The principal publications of the Division of Mines are the quarterly **California Journal of Mines and Geology**, issued in January, April, July, and October of each year, and a series of **Bulletins. Mineral Information Service** is a monthly news release concerning the mineral resources and industry of California, designed to inform the public of discoveries, operations, markets, statistics, and new publications. It is distributed without cost upon request. A list of publications will also be sent free upon request.



MAP OF
CALIFORNIA
SHOWING THE
DISTRIBUTION OF PRINCIPAL MINERAL RESOURCES
PREPARED BY THE
STATE DIVISION OF MINES
SCALE
1945
OREGON
DEL NORTE
SISKIYOU
MODOC
SHASTA
LASSEN
HUMBOLDT
TRINITY
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
NEVADA
PLACER
MENDOCINO
COLUSA
YUBA
SUTTER
LAKE
EL DORADO
SONOMA
YOLO
NAPA
SOLANO
SACRAMENTO
ALPINE
AMADOR
CALAVERAS
MARIN
SAN JOAQUIN
TUOLUMNE
MONO
CONTRA COSTA
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
SAN BENITO
FRESNO
INYO
MONTEREY
KINGS
TULARE
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
MEXICO
ARIZONA
PACIFIC
OCEAN
MINERAL RESOURCES
ANDALUSITE & KYANITE
BARITE
BORAX
BUILDING STONE
CARBON DIOXIDE GAS
CHROMITE
CLAY
COAL
COPPER
DIATOMITE
DOLOMITE
FELDSPAR
FELDSPAR & SILICA (QUARTZ)
GOLD DISTRICTS
GOLD (SMALL AREAS OR MINES)
GYPSUM
IRON
LEAD
LIMESTONE, CEMENT & MARBLE
MAGNESITE
MANGANESE
POTASH
PUMICE & VOLCANIC ASH
PYRITES
QUICKSILVER
SALT
SILICA (QUARTZ)
SILICA (SAND)
SILVER
SODA
SULFUR
TALC & SOAPSTONE
TITANIUM
TUNGSTEN
ZINC
GAS DISTRICTS
OIL & GAS DISTRICTS
CITIES
NOTE
COMBINED SYMBOLS SHOW TWO OR MORE MINERALS OCCUR AT SAME LOCALITY
BORAX, SODA
COPPER, ZINC

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THE BASEMENT COMPLEX IN WELL SAMPLES FROM THE SACRAMENTO AND SAN JOAQUIN VALLEYS, CALIFORNIA

By J. C. May * and R. L. Hewitt **

OUTLINE OF REPORT

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* District Geologist, San Joaquin Valley, Tide Water Associated Oil Company, Associated Division.
** Geologist, Tide Water Associated Oil Company.
Manuscript submitted for publication October 1947.

INTRODUCTION

The purpose of this paper is to present the results of a general examination of approximately 184 thin sections of ''basement complex'' rocks, cored in wells drilled for oil and gas, mostly on the east side of the San Joaquin and Sacramento Valleys. These cores come from depths ranging from 492 to 13,664 feet. A few thin-section determinations of igneous and metamorphic rock outcrops, in the southeastern part of the San Joaquin Valley, are included.

This collection of thin sections and available hand specimens is to be filed at the California Academy of Sciences, San Francisco, California, for further study. It is hoped that the collection and preservation of these samples will aid the knowledge of the geology of the ''basement complex'', between the Sierra Nevada and the Coast Ranges.

The term ''basement complex'' includes all of the various igneous and metamorphic rock types, predating the earliest Cretaceous of the Great Valley. Basement rocks are overlain by sediments of varying hardness and texture, ranging in age from Cretaceous to Quaternary. The surface of the basement complex may be fresh to deeply weathered, depending on the hiatus, and conditions of weathering between the exposure of the older rock, and the cover by later sediments.

The form and extent of the igneous and metamorphic areas are in general unknown, because of the sedimentary mantle. Hints as to the shape of a few of these bodies have been obtained in the intensely drilled areas, such as the Edison oil field in the southern San Joaquin Valley.

In 1945, oil was discovered in the metamorphic rocks of the Edison oil field, and resulted in active development of oil from this series. As a consequence, more interest is being given to the possibilities of oil from the basement elsewhere. Basement production is unusual in the record of petroleum discovery and development. This does not mean that it is unique. The persistent search by the petroleum industry for oil and gas can lead to further discovery under suitable geologic and structural conditions.

ACKNOWLEDGMENTS

The present study originated from a suggestion by Dr. G. D. Hanna, of the California Academy of Sciences and the Tide Water Associated Oil Company, of San Francisco. He wished to have approximately 25 samples of basement cores, from wells strategically located in the San Joaquin and Sacramento Valleys, examined microscopically, and to file the determinations and slides at the California Academy of Sciences. This modest aim has grown into a set of over 200 slides from the Valley alone, and 193 of these were used in the preparation of this paper.

All of the oil companies and operators listed on the index of samples were most helpful in allowing the data on their samples to be published. In addition, the writers wish to thank the Shell Oil Company for furnishing a set of 52 samples from old wells; and the Honolulu Oil Corporation for use of their set of petrographic slides. The Jergins Oil Company was very cooperative in supplying a large suite of sidewall samples from the Edison oil field. This suite was most useful in preparing the map showing basement rocks of the Edison field (pl. 10). The Tide Water Associated Oil Company provided most of the thin sections. The Company is thanked for permission to publish this report.

Individuals who aided the writers in the collection of samples are: E. W. Adams, T. Barnes, J. H. Beach, T. K. Bowles, J. Brodek, J. J. Bryan, R. W. Burger, H. A. Campbell, S. A. Carlson, S. A. Champion, C. C. Church, M. N. deLaveaga, T. K. Fitzgerald, J. D. Gilboe, O. Hackel, R. Haynes, B. Herndon, J. D. Hale, F. A. Hewitt, M. L. Hill, A. S. Huey, A. G. Ison, H. A. Kelley, J. E. Kilkenny, W. S. Knouse, G. W. Ledingham, W. Matjasic, D. C. May, F. A. Menken, E. W. Pease, C. W. Porter, L. W. Saunders, D. E. Taylor, C. E. Van Gundy, A. W. Vitt, R. N. Williams Jr., and W. P. Winham.

The authors are indebted to Dr. Olaf P. Jenkins, Chief of the Division of Mines, for furnishing the state geologic map (uncolored) which was used to locate the wells from which samples were taken. Mr. Paul Baldwin of Bakersfield assisted with the photographic illustrations.

THE IGNEOUS ROCKS

Igneous rocks have been found in wells throughout almost the entire length of the San Joaquin and Sacramento Valleys. They range in composition from ultrabasic to granite. In size, the intrusive bodies range from the Sierra Nevada batholith down to strictly local dikes or small sheets.

Generally the variation in composition of a single intrusive is slight, even though the body may be batholitic in extent. Rapid differentiation, however, has been observed locally.

The nomenclature of the igneous rocks has necessarily been obtained from hand-specimen and microscopic examinations, but it has been restricted to the terminology most commonly applied in the outcrop.

The various rock types, for the sake of convenience, will here be described, generally, in their ascending order of acidity.

Hornblendite

Occurrence. Two samples of hornblendite were found in widely separated wells, as follows:

1. Jergins Oil Company ''California Grape'' No. 18, sec. 17, T. 23 S., R. 26 E., M. D.
2. Standard Oil Company No. 72-21, sec. 21, T. 29 S., R. 29 E., M. D.

The extent of these bodies is unknown, but is assumed to be small, as Grout [1] states that they ''occur rarely except as segregations in relatively small bulk related to other intrusives''.

Petrography. The hornblendite rocks are black to dark greenish, fine to medium grained or phanerocrystalline, and very hard. Microscopically they appear holocrystalline with euhedral to anhedral crystals, and the texture locally appears semi-diabasic to hypidiomorphic (pl. 12*A*).

The feldspar, which comprises from 1 to 10 percent of the rock, ranges from calcic labradorite in the Standard Oil Company No. 72-21 well in sec. 21, T. 29 S., R. 29 E., M. D., to bytownite in the Jergins Oil Company ''California Grape'' No. 18 well in sec. 17, T. 23 S., R. 26 E., M. D. Under the microscope it is seen to be stubby, lath-shaped, and murky, and locally to contain abundant inclusions of accessory minerals. Zoning is not pronounced, but does occur. Albite twinning is very common, the twinning lamellae being quite broad.

[1] Grout, F. F., Petrography and petrology, p. 107, 1932.

Orthoclase was noted as a trace in one sample.

Quartz comprises 5 percent of the rock in the Standard Oil Company No. 72-21 well, but was not noted in the other. Some of this quartz may be primary in origin, but most of it is believed to be secondary, as it occurs in small veinlets and exhibits a recrystallized character.

The ferromagnesian minerals consist of hornblende, actinolite, tremolite, hypersthene, augite, aegirine-augite, and biotite.

The hornblende, which makes up from 55 to 76 percent of these rocks, is greenish, but its composition is probably intermediate between the green and brown varieties, as it has a pleochroic formula: X = pale brown, Y = green, Z = dark green. A prismatic habit is the most common, but there is considerable variation, ranging from roughly equidimensional anhedral grains to euhedral crystals. It is rarely twinned. A few crystals poikilitically enclose small euhedral feldspar. "Reaction-like" rims around some of the grains may denote deuteric action, or possibly zoning.

Actinolite occurs in one of the localities as small bluish-colored acicular prisms. A trace of tremolite is also present.

Hypersthene composes approximately 5 percent of these rocks. It occurs as subhedral prisms with typical pinkish to dull green pleochroism. No schiller structure was noted.

The augite, which is uncommon, is a pale greenish or colorless variety, that occurs as individual crystals or remnants associated with hornblende. Aegirine-augite also occurs under similar conditions.

Traces of biotite were found in one sample, but its percentage was too low to reveal a common habit.

The accessory minerals are magnetite, pyrite, zircon, apatite, and titanite. Magnetite is present in small amounts in all sections as well-formed crystals and irregular grains. Pyrite usually occurs as irregular grains, but is rare. Apatite exhibits a short prismatic habit and is found only in small amounts. Zircon and titanite generally occur in minor quantities as rounded grains.

Dynamo-thermal metamorphism has altered these rocks to varying degrees. The sample from the Jergins Oil Company "California Grape" No. 18 well in sec. 17, T. 23 S., R. 26 E., M. D., is relatively unaltered, but the plagioclase shows undulatory extinction, and there is a considerable amount of antigorite and calcite present as replacements of original minerals.

The Standard Oil Company No. 72-21 sample, sec. 21, T. 29 S., R. 29 E., M. D., is more severely altered. Stress effects such as undulatory extinction both in the plagioclase and hornblende are very common. The edges of both these minerals are highly serrate and much of the hornblende shows shredding. Chlorite, clinozoisite, epidote, and sericite are present in appreciable amounts. There may have been some hydrothermal action in this vicinity as secondary quartz and calcite were noted in veinlets.

GABBRO

Occurrence. Gabbroid rocks have been encountered in wells from the Marysville Buttes, in the Sacramento Valley, south to the vicinity of Bakersfield. They can be grouped geographically as follows: (1) Marysville Buttes, Sutter County; (2) Hayden Hill, near Dinuba, Tulare County; (3) Rio Bravo-Greeley area, Kern County; (4) Race Track Hill, Kern County.

The size and nature of these bodies have not been determined by drilling, but they are believed to range from small dikes, or plugs to intrusives closely akin to a batholith.

Petrography. Hand samples of the gabbros are gray, dark greenish, or black, fine to coarse-grained, holocrystalline, hypidiomorphic to granitoid, hard, massive rocks. Plagioclase, amphibole, pyroxene, and magnetite are common.

Microscopically, the gabbros appear holocrystalline with textures varying from granitoid to ophitic. These textures are the result of normal and reverse-order crystallization, a situation commonly found in rocks of the gabbro clan. The rocks in which the granitoid texture is present often show well-rounded amphiboles and pyroxenes, indicating that they were resorbed in part by the magma before the plagioclase crystallized (pl. 12*B*). The Race Track Hill sample is porphyritic, with well-developed phenocrysts common in a holocrystalline, fine-grained groundmass. The phenocrysts are from 10 to 20 times as large as the average groundmass crystal.

Bytownite of varying composition is the common plagioclase. It comprises from 40 to 69 percent of the rock in the slides studied. It exhibits anhedral to euhedral forms in roughly equidimensional grains, or long, narrow, lath-shaped crystals. Polysynthetic twinning is always present and the twinning lamellae vary considerably in width. Pericline and carlsbad twinning are rare. Zoning is uncommon, but is locally surprisingly well developed. The crystals are usually clear but may carry inclusions of apatite.

Orthoclase in minute amounts may or may not be present.

The ferromagnesian minerals consist of horneblende, hypersthene, augite, aegirite, aegirine-augite, biotite, and olivine, although these minerals were never all found together in the same rock. Hornblende, hypersthene, augite, and biotite are found most frequently.

Hornblende, which comprises from 2 to 20 percent of these rocks, may be colorless, greenish, or brownish, and weakly to strongly pleochroic. It forms well-rounded anhedral grains, but may be subhedral, or crystallize as small, narrow, prismatic crystals. Twinning and schiller structure occasionally are found. Hornblende sometimes forms "reaction-like" rims as a deuteric alteration of augite.

Augite, which is usually present in amounts up to 22 percent of the rock, exhibits a form similar to hornblende. Aegirine-augite in anhedral grains frequently is present in amounts up to 25 percent. It occasionally shows alteration rims and contains numerous opaque inclusions. Aegirite, which is colorless or slightly pleochroic, is uncommon.

Hypersthene is rare. It forms anhedral grains which locally are characterized by magnetite inclusions and schiller structure.

Biotite is uncommon as a rule, but where present consists of either brownish or greenish varieties which are strongly pleochroic.

Olivine was recognized only in the Race Track Hill sample. It forms anhedral grains with polygonal outlines, or euhedral to subhedral crystals, as inclusions in the bytownite phenocrysts. It makes up approximately 5 percent of the mineral content of this sample.

The accessory minerals consist of magnetite, pyrite, chromite, zircon, and apatite. Magnetite and zircon are the most common. They all exhibit irregular shapes except zircon and apatite which sometimes form small euhedral crystals.

The gabbroid rocks are only slightly affected by weathering and dynamothermal metamorphism. A few show minute fracturing and undulatory extinction. Chlorite, rarely as pennine, forms small veinlets or attacks the edges and cores of the femic minerals. Epidote and clinozoisite are found in similar positions. Kaolin and paragonite may be associated with the bytownite as coatings. Calcite is present in a few veinlets. The Race Track Hill sample shows a rude orientation of the biotite and hornblende denoting incipient schistosity.

Relationship of the Gabbroid Rocks. The relationship of the above widely separated areas of gabbroid rocks can only be surmised, but a few observations are possible. The Marysville Buttes body, because of its medium-grained granitoid texture and the fact that other igneous rocks of a more acid composition are present in the vicinity, is thought to be a deep-seated dike or small plug. It may be intrusive into the more acid rocks and the same age as the Miocene basalts of the Sacramento Valley, or it may be an early differentiate of the same magma that produced the more acidic rocks.

The gabbro of Hayden Hill forms the core of an intrusion which becomes more acid outward, grading through diorite to quartz diorite. It may be a small deep-seated intrusion of a later age than the more acid rocks surrounding it, or an offshoot of an old gabbroid area to the west. If this is the case, the more acid rocks may be differentiates of the parent gabbro.

The Rio Bravo-Greeley region with its typical gabbroid variation in textures, but relatively uniform mineral content, could represent a part of a large area of heavy, basic rocks. This region has been a negative one since early Mesozoic time and a thick succession of sediments has been laid down on it. It is thought, in general, that eastward from this area the rocks become more acid and the intrusions progressively younger.

The Race Track Hill body, because of its porphyritic texture and well-crystallized groundmass, is thought to be a small deep-seated intrusion. The relationship of this intrusion to the Rio Bravo-Greeley gabbro is unknown. The presence of olivine in this rock, which was not found in the latter area, may indicate a somewhat different source.

Diabase

Occurrence. Diabase basement rocks are most common along the east side of the San Joquin Valley, from the vicinity of Hanford south to the extreme tip of the Valley. No diabase has been encountered north of Hanford, except in one well approximately 15 miles east of Willows, in the Sacramento Valley. The diabase bodies are thought to be small dikes and sills.

Petrography. The diabases are dark-gray, greenish-gray, brownish or black, fine- to medium-grained rocks. They appear to be holocrystalline and are even grained, hard, massive, and dense. Magnetite and pyrite, as well as plagioclase and the femic minerals usually can be recognized in hand specimens.

Under the microscope, the minerals exhibit a reverse order of crystallization, and the rocks possess ophitic texture (pl. 13*A*). The relative size of the different crystals may vary considerably and thus give a slightly different appearance.

The plagioclase in these rocks is generally labradorite, with one exception; in the General Petroleum Corporation's "Calloway" No. 66 well,

sec. 17, T. 29 S., R. 27 E., M. D., the plagioclase was andesine. This latter rock, however, borders on diorite in composition and may be a differentiate of the main valley gabbro, rather than a true diabase.

The labradorite usually occurs as long, thin, anhedral to euhedral laths which may be five to ten times as long as they are wide. Polysynethetic twinning is always present and the laths may contain from three to five laminae across, which differ somewhat in width. Pericline and carlsbad twinning are uncommon, but were noted in the sample from the Superior Oil Company ''Dodge Land'' No. 1 well, sec. 31, T. 20 N., R. 1 E., M. D., east of Willows; and in the Turner ''Glaze'' No. 1 well, sec. 15, T 22 S., R. 26 E., M. D. The labradorite is generally clear, but locally may contain inclusions of epidote, clinozoisite, and magnetite. Labradorite comprises from 40 to 60 percent of the mineral content of the diabase.

Orthoclase occurs as a trace in the rock from the Superior well mentioned above, and comprises 3 percent of the diabase from General Petroleum Corporation's ''Calloway'' No. 66 well.

The ferromagnesian minerals consist of hornblende, actinolite, tremolite, hypersthene, augite, aegirine-augite, and biotite. Hornblende is the most abundant femic mineral in most of the samples, comprising from 5 to 31 percent. It was not found in the diabase in the Reserve Oil and Gas Company's No. 3 well, sec. 12, T. 10 N., R. 19 W., S. B. Deeper drilling and areal mapping, however, indicate that this diabase is not ''basement,'' but is related in age to the interbedded Miocene extrusives of the district. Hornblende is only a minor constituent in the sample from the Superior Oil Company's ''Dodge Land'' No. 1 well. It is generally very pale green to light brown or almost colorless, and only slightly pleochroic. It exhibits an anhedral form.

Actinolite occurs in minor amounts as small needles or fibres. One sample from the Jergins Oil Company ''Handel'' No. 1 well, sec. 23, T. 30 S., R. 29 E., M. D., which is believed to be a diabase, contained 15 percent actinolite. This rock has been severely metamorphosed.

Tremolite is rare. It occurs as fibrous aggregates, possibly as an alteration product of pyroxene in the Reserve Oil and Gas Company No. 3 well, sec. 12, T. 10 N., R. 19 W., S. B.

Hypersthene comprises from 3 to 5 percent of most of the diabase examined. It occurs as anhedral grains and crystallized about the same time as the other pyroxenes.

Augite and aegirine-augite are quite common and make up from 5 to 35 percent of the mineral assemblage. They may or may not be found together.

Biotite was noted in only one sample, that from the Reserve Oil and Gas Company No. 3 well mentioned above. It possessed a strong yellowish to reddish-brown color and appeared partially altered to limonite.

The accessory minerals consist principally of magnetite and pyrite, which usually occur as irregular masses or specks. Traces of ilmenite with accompanying leucoxene, zircon, titanite, and graphite were noted.

Most of the diabase rocks are fresh, but a few are badly altered. Epidote and clinozoisite are common, indicating that some of the femic minerals altered early. Chlorite, especially violet or ''wine-colored'' pennine, is fairly common especially in the more altered samples. Calcite is present in all the samples as a minor alteration product. The effects of metamorphism on the diabase will be discussed later.

Basalt (Tachylyte)

The only sample of basalt (tachylyte) encountered in this study was cored in the Pacific Western—Getty "Independent Exploration—Cana" No. 1 well, sec. 11, T. 23 N., R. 1 W., M. D., northwest of Chico in Butte County. It is a dark greenish to black rock which is very fine grained, hard, dense, and minutely fractured. Beds containing Chico (Cretaceous) fossils were found resting upon this rock.

Petrography. Microscopically the tachylyte appears vitreous, and originally consisted almost entirely of basaltic glass. This glass has been thoroughly fractured, and the fractures now form an anastomosing network of chalcedony veinlets (pl. 13 *B*). The predominant chalcedony assumes a fibrous habit, with the fibres oriented across the fractures. It also exhibits a spheroidal pattern in the wider fractures. The glass appears to be devitrifying locally, and small areas have altered to calcite. A trace of enstatite, as small subhedral crystals, was noted. Magnetite and pyrite appear disseminated throughout the glass, and magnetite forms irregular to rounded masses. There is minor chlorite alteration along some of the fractures.

This rock is thought to be of volcanic origin and may represent part of an old surface flow.

Acid Plutonic Rocks

The igneous rocks included in the acid plutonic group are those closely related to the Sierra Nevada batholith. They range in composition from diorite to granite. Quartz diorite is by far the most common type found. They will first be described petrographically in an ascending order of acidity; then their distribution will be discussed as a means of correlating the various types in the field.

Diorite

Petrography. Diorite hand specimens are mottled, medium-gray and black rocks, which may alter to grayish green or yellowish green and black. They are most commonly coarse grained, holocrystalline, hard, dense, and massive.

Thin-section study confirms the holocrystalline granitoid texture of the diorites. The minerals are coarsely crystalline and show anhedral to subhedral form. Mineralogically the diorites are quite simple, and resemble the quartz diorites closely. The major difference between the two types is, of course, the absence of quartz in the diorites, and a generally slightly lower percentage of plagioclase feldspar.

The plagioclase feldspar is nearly always andesine with a composition of approximately Ab_6An_4. One exception to this was found in the specimen from Buttes Oil Field Company, Ltd. "Sophie Davis" No. 2 well, sec. 35, T. 16 N., R. 1 E., M. D., in which the plagioclase is bytownite. This rock, however, appears to be more basic than a normal diorite.

Orthoclase was found only in the Union Oil Company "Archibald" No. 1 well sample, sec. 14, T. 10 S., R. 19 E., M. D., in which it made up 10 percent of the mineral content.

The ferromagnesian minerals in the diorites consist of hornblende, hypersthene, aegirine-augite, augite, aegirite, enstatite, biotite, and muscovite. The form and habit of these minerals are the same in the quartz diorites and will be discussed more fully under that heading.

The accessory minerals consist of magnetite, pyrite, zircon, apatite, and garnet. Magnetite is chiefly irregular in shape, but may be subhedral. Pyrite is disseminated as small grains. Zircon and apatite commonly exhibit a subhedral to euhedral form. Garnet is very rare.

The diorite samples examined were fresh, but some alteration was noted. Epidote, chlorite, pennine, and clinozoisite are commonly associated with the pyroxenes and amphiboles. They attack the edges of the crystals and along cleavages. Chlorite was found in veinlets. The cores of some of the zoned plagioclase alter to calcite. Kaolin, sericite, and paragonite were found in minute quantities.

Quartz Diorite

Petrography. The quartz diorites are here restricted to the quartz-bearing rocks in which less than $13\frac{1}{3}$ percent of the total feldspar present is orthoclase. Even with this restriction, approximately one-third of the total number of samples examined were quartz diorite. These rocks are mottled light to medium gray or translucent gray and dark, greenish-black to glassy black. They are holocrystalline, coarse to very coarse grained, but locally may be somewhat finer. They consist of quartz, plagioclase, and biotite, but occasionally amphiboles and pyroxenes are present. The quartz sometimes has an ''opaline blue'' color.

Microscopic study indicates that the quartz diorites all have a granitoid texture (pl. 14*A*). A few of them, where affected by stress, are recrystallized and show a rude orientation of the minerals. The normal order of crystallization predominates, but locally, in femic-rich samples, the reverse order may be seen. They are mineralogically simple.

Quartz is present in amounts from 2 to 43 percent, but the average appears to be between 10 and 15 percent. It is nearly always anhedral and appears to be interstitial with regard to the other minerals. It often shows strained extinction.

Andesine, of a somewhat varying composition, was found to be the plagioclase feldspar in all the samples examined. It is present in amounts from 20 to 70 percent. It is generally anhedral to subhedral in shape, whether in equidimensional grains or laths of various widths. Zoning is common and gives some of the plagioclase crystals a euhedral, stubby prismatic appearance, but the outer layer of these crystals is usually subhedral. Polysynthetic twinning is always present and other types of twinning may occasionally be recognized. The andesine is clear as a rule, but inclusions of earlier minerals sometimes are found.

Orthoclase comprises from 5 to 10 percent of the mineral assemblage. It is anhedral and rarely twinned. Orthoclase was lacking in samples which were high in ferromagnesian minerals.

The ferromagnesian minerals, although always present, are not as plentiful as in the diorites. They consist of biotite, muscovite, hornblende, hypersthene, augite, and aegirine-augite. Biotite is consistently present. It makes up from a trace to 30 percent of the rock, but is most common in amounts of 5 to 10 percent. It exhibits numerous tints and shades of green and brown in subhedral prismatic crystals and irregular grains. Often it contains inclusions of feldspar, magnetite, and other minerals.

Hornblende, although common in some localities in amounts up to 45 percent, generally is found in only minor quantities or is absent. It is a pleochroic light-green to light-brown variety, which forms subhedral to anhedral grains. Inclusions of plagioclase are rare, but when present give the hornblende a local poikilitic texture.

Hypersthene, augite, aegirine-augite, and other femic minerals are rare and their habit is much the same as hornblende. They are locally poikilitic or exhibit schiller structure.

The most common accessory minerals are magnetite, pyrite, zircon, apatite, and garnet. Their habit is similar to that found in the diorites. Ilmenite, chromite, titanite, tourmaline, and monazite are very rare.

Garnet is remarkably common in the quartz diorites. It is usually present as small dodecahedral crystals in biotite, but may form inclusions in plagioclase. The crystals are too small to determine their variety name. Garnet is an unusual accessory mineral in this type of igneous rock. Large almandite garnet crystals from a diorite found in the southern San Joaquin Valley have been described by Schürmann[2] and Murdock[3]. The latter writer believes that these garnets, which contain numerous plagioclase impurities, were formed either as phenocrysts, or by replacement of the diorite shortly after its intrusion into a series of metamorphosed sediments. The garnets found in the present work were associated principally with quartz diorites and granodiorites. They are very small, free of inclusions, but commonly are inclusions themselves. It is thought, therefore, that they are a primary accessory mineral.

The quartz diorites, except in the Rag Gulch area, are fresh; and the same alteration products, as in the diorites, were found in minor amounts. The Rag Gulch area, however, appears to have been deeply weathered, as nearly all quartz diorite samples show high percentages of chlorite, epidote, clinozoisite, sericite, and kaolin.

Deuteric effects such as myrmekite, and reaction rims of hornblende on augite, were noted in a few samples.

Granodiorite

Petrography. The term granodiorite is here applied to the quartz-bearing plutonic rocks in which from one-third to $13\frac{1}{3}$ percent of the total feldspar is orthoclase. Megascopically the granodiorites are mottled gray and black, coarse-grained, holocrystalline rocks similar to the quartz diorites. Microscopically they have a granitoid texture. Their mineral assemblage and habit are identical to those of the quartz diorites, the only difference being in the percentages of the constituents. Andesine is the plagioclase feldspar; it occurs in amounts from 20 to 56 percent (pl. 14*B*). Orthoclase is much more common, comprising from 5 to 17 percent of the rock. The ferromagnesian minerals are rare, with the exception of biotite, which makes up 3 to 30 percent in the samples studied. The accessory minerals consist of magnetite, pyrite, zircon, apatite, and garnet. Most of the samples examined showed some alteration to epidote, chlorite, clinozoisite, calcite, and sericite, and minor veinlets of chalcedony. Late magmatic alterations were noted in the development, in a few cases, of myrmekitic intergrowths.

Quartz Monzonite

Petrography. Quartz monzonite is considered by the writers to include the quartz-bearing plutonic rocks in which from one-third to two-thirds of the total feldspar is orthoclase. It is a coarse-grained, holocrystalline rock with much the same appearance as a granodiorite or

[2] Schürmann, H. M. E., Granatführender Diorit aus der Sierra Nevada Kalifornien; Neues Jahrb., Beilage Band 74, Abt. A, Heft 2, pp. 225-250, 1938.

[3] Murdock, Joseph, Some garnet crystals from California: Jour. Geology, vol. 47, pp. 189-197, 1939.

quartz diorite. The microscopic appearance is also very similar. The texture is granitoid with interlocking anhedral to subhedral grains. Zoning is present in the plagioclase. Quartz is always present. Orthoclase is much more common than in any of the previously mentioned rocks. The plagioclase is predominantly oligoclase of varying composition, although one sample contained andesine. Biotite is very common in amounts from 3 to 10 percent. Hornblende and aegirine-augite were found in only one locality, and no other primary ferromagnesian minerals were noted. The accessory minerals consist of magnetite, pyrite, zircon, and apatite. The common alteration products noted above are present in minor amounts. The quartz monzonites are quite frequently fractured and exhibit chalcedony veinlets. Myrmekitic intergrowths are somewhat more common than in the more calcic rocks.

Granite

Petrography. Granite here embraces the quartz-bearing plutonic rocks in which more than two-thirds of the total feldspar is orthoclase. It is rather a rare rock type in the region under consideration. It is, where fresh, speckled to mottled light gray and black, medium to coarse grained, and holocrystalline. Quartz, feldspar, and biotite are prominent. Most of the granite samples examined were badly altered, probably by weathering, to mottled greenish-gray and black.

The microscopic character of the granites closely resembles the other members of the acid plutonic group. The texture is granitoid. Quartz is very common in all samples. Orthoclase is the principal feldspar and oligoclase may or may not be present. Biotite is the most common femic mineral, although traces of hornblende and augite were noted. Magnetite, pyrite, zircon, and apatite are frequent accessory minerals. Ilmenite, titanite, garnet, and tourmaline are rare. Many of the samples studied were badly altered; in these, chlorite, clinozoisite, sericite, and chalcedony were common, as were zoned plagioclase crystals and myrmekitic intergrowths.

Distribution and Relationship of the Acid Plutonic Rocks

The acid plutonic rocks may be grouped into the following areas: (1) Sacramento Valley north of Stockton, San Joaquin County; (2) Madera, Madera County; (3) Kingsburg, Fresno County, and Hayden Hill area, Tulare County; (4) Terra Bella, Tulare County; (5) Rag Gulch, Kern County; (6) Bakersfield, Kern County; (7) Edison—Mountain View, Kern County.

Sacramento Valley North of Stockton, San Joaquin County. This area contains only three wells which encountered acid plutonic rocks. The two most northerly wells, the Buttes Oil Field, Ltd. "Sophie Davis" No. 2 well, sec. 35, T. 16 N., R. 1 E., M. D., on the Marysville Buttes, and the Bankline Oil Company "Community" No. 1 well, sec. 1, T. 4 N., R. 6 E., M. D., near Galt, San Joaquin County, found diorites. The Richfield Oil Corporation "Stockton" No. 1 well, sec. 5, T. 1 N., R. 8 E., M. D., east of Stockton, entered a quartz diorite. Since these wells are so far apart, the relationship of the diorites, if any, is unknown.

Madera, Madera County. A number of wells north and east of Madera bottomed in acid plutonic rocks which range in composition from diorite to quartz monzonite. This area lies immediately southwest of a quartz diorite outcrop, south of an area of sedimentary schist. The Union

Oil Company ''Floto'' No. 1, sec. 5, T. 11 S., R. 18 E., M. D., immediately to the west, encountered a meta-sediment. The diversity of rock types may indicate that this area occupies a marginal position with regard to the Sierra Nevada batholith, in which considerable magmatic differentiation took place, and roof pendants were common.

Kingsburg, Fresno County, and Hayden Hill Area, Tulare County. The Superior Oil Company ''White'' No. 1 well, sec. 29, T. 16 S., R. 22 E., M. D., a few miles west of Kingsburg, bottomed in quartz diorite. The Kingsburg quartz diorite area is separated from the Hayden Hill area to the east by an area in which sedimentary schist was encountered by the Transcal Drilling Company ''Harris'' No. 1 well, sec. 34, T. 16 S., R. 23 E., M. D. The core of Hayden Hill has been described under the gabbros. Immediately south of this core, diorite was found in the Amerada Petroleum Corporation ''Community'' No. 28-1 well, sec. 28, T. 16 S., R. 24 E., M. D. Farther south, in the Winnifred Schneider ''Pritchett'' No. 1 well, sec. 1, T. 17 S., R. 24 E., M.D., quartz diorite was cored. Hayden Hill may represent differentiation from gabbro to quartz diorite in a local intrusion, or the more basic rocks may be of a different age. The quartz diorite apparently extends beneath the sedimentary schist, westward to the Kingsburg area.

Terra Bella, Tulare County. Several wells encountered quartz diorite basement rocks in the old Terra Bella oil field and in the immediate vicinity of Terra Bella. This group of wells is surrounded on three sides by areas of sedimentary schist, but is open to the quartz diorite outcrop to the southeast. Therefore, it is thought that the wells mark an igneous ''high,'' which is a northwest extension of the quartz diorite in the outcrop.

Rag Gulch, Kern County. The Rag Gulch area is east of the towns of Delano and McFarland, Kern County, between townships 24 and 27 south, Mount Diablo Meridian. Approximately 25 wells have been drilled in this area, which have encountered igneous basement rocks. The great majority of these rocks are quartz diorites. The Tide Water Associated Oil Company ''Quinn'' No. 46 well, sec. 8, T. 25 S., R. 27 E., M. D., Wilshire Annex Oil Company ''Amalgamated'' No. 1 well, sec. 17, T. 25 S., R. 28 E., M. D., and the Shell Oil Company ''Knapp'' No. 2 well, sec. 28, T. 26 S., R. 28 E., M. D., are exceptions in this area: they encountered granite. The Fred Jasper ''Jasper'' No. 1 well, sec. 16, T. 26 S., R. 27 E., M. D. and the Chanslor-Canfield Midway Oil Company ''Jasmin'' No. 1 well, sec. 23, T. 25 S., R. 27 E., M. D., located in the central portion of the Rag Gulch area, cored granodiorite. Quartz monzonite was found in the Chanslor-Canfield Midway Oil Company ''Famoso'' No. 12 1, sec. 12, T. 27 S., R. 26 E., M. D., and the Superior Oil Company No. 1, sec. 13, T. 27 S., R. 28 E., M. D. One characteristic which is common to all the rocks of the Rag Gulch area is that they are intensively altered by weathering. The area probably represents a basement high which underwent deep weathering before submergence. The slight variation in rock types may represent local differentiation of the magma, or several intrusions, the sequence of which is unknown.

Bakersfield, Kern County. Quartz diorite and granodiorite of an almost similar composition and appearance comprise the main basement rocks to the north and east of the city of Bakersfield. Roof pendants of sedimentary schist are known in this area and will be discussed later. Numerous fine-grained intrusions, dioritic or quartz dioritic in compo-

sition, are found throughout the area. Their relationship to the coarse-grained basement rocks will be evaluated in another section.

Edison-Mountain View, Kern County. The Edison-Mountain View area includes the relatively unaltered basement rocks east of the Edison and Mountain View oil fields in townships 30 to 32 south, Mount Diablo Meridian, inclusive. With one exception, these rocks are quartz diorites and represent an extension of the main Sierra Nevada batholith, which lies immediately to the east. The Ohio Oil Company ''Cauley'' No. 2 well, sec. 36, T. 30 S., R. 29 E., M. D., which lies well within the main quartz diorite area, encountered quartz monzonite. This may represent a locally more acidic portion of the general magma, or may be a later differentiate.

Hypabyssal Intrusives

The hypabyssal intrusives include the following rock types: aplite, malchite, diorite aplite, diorite porphyry, lamprophyre, and andesite. They occur principally as deep-seated intrusive sheets, such as laccoliths, sills, and dikes; but a few, including the andesite, are thought to be somewhat shallower-seated.

The general appearance of these intrusives is very similar. They range from light to dark gray, gray green, greenish tan to dark green, depending upon their degree of alteration. They are usually fine grained, but some are medium grained. They are massive to slightly schistose, and hard. The mineral constituents can be determined only broadly in the hand specimen. Large phenocrysts occasionally indicate coarser-grained porphyries.

Petrography

Microscopically the hypabyssal intrusives are nearly all porphyritic. Phenocrysts, consisting of both salic and femic minerals, range in size from 10 to 40 times that of the groundmass crystals. The larger phenocrysts occur in the andesite. Some phenocrysts are euhedral in shape, but most are subhedral to anhedral. The groundmass is always holocrystalline, but the andesites may contain some glass. The groundmass is usually aphanitic in grain size, but may range to finely phanerocrystalline. It is aplitic to finely granitoid in texture, or may consist of a very fine ''felt-like'' mass. In many instances recrystallization has produced interlocking mosaics. A few samples exhibit a tendency to be diabasic in texture. Holocrystalline samples without phenocrysts are here classified as aplites.

The hypabyssal intrusives are mineralogically simple and consistent. The presence or absence of quartz in holocrystalline samples was used to separate malchites from diorite aplite and porphyry. This method was used in classifying the Richfield Oil Corporation ''Tulare Community'' No. 1 sample, sec. 33, T. 19 S., R. 24 E., M. D., in which some glass was present, as a dacite rather than an andesite. Quartz, where found, comprises from 2 to 20 percent of the rock. It usually is recrystallized and shows strain shadows.

Orthoclase is present in most samples in minor amounts up to 5 percent; however, none was noted in the andesites. It is always anhedral and most often recrystallized without twinning.

Andesine is the plagioclase feldspar in all but one of the samples studied. The exception is the specimen from Federal Oil Company ''Federal-Omaha'' No. 1 well, sec. 21, T. 30 S., R. 29 E., M. D., in which the

plagioclase is labradorite. Andesine makes up from 40 to 50 percent of the rocks as a rule, but was found to vary from 3 to 70 percent. It usually occurs as subhedral laths, from stubby to long and narrow in shape. Andesine phenocrysts are more equidimensional. Polysynthetic twinning is very common, but occasionally is destroyed by recrystallization. Pericline and carlsbad twinning are rare. Zoning is sometimes present, but is not nearly so prevalent as in the plutonic intrusives. Inclusions of epidote and clinozoisite are fairly common.

Muscovite is rare, but was found in a few samples in which the pyroxenes were few or absent.

The ferromagnesian minerals consist of hornblende, actinolite, tremolite, hypersthene, augite, aegirine-augite, aegirite, and biotite. The most common is hornblende, which in general makes up from 15 to 20 percent of the rock. Most of the hornblende is subhedral, but one sample showed a remarkable development of euhedral crystals. The hornblende is pale green, brownish, or colorless and weakly pleochroic. Some twinning is present. In samples in which incipient schistosity is present, hornblende crystals exhibit shredding.

Next to hornblende, biotite is the most common mineral, being present in amounts from 1 to 14 percent. It is brownish or greenish in color, pleochroic, and usually subhedral in shape. It frequently shows the effect of stress by being bent.

Actinolite and tremolite are fairly common in minor amounts, and appear very similar to hornblende, from which they can only be separated by their optical properties.

The pyroxenes, including aegirine-augite, hypersthene, augite, and aegirite, are present, especially in the Edison area of the San Joaquin Valley. They are all found in minor amounts, except aegirine-augite, which may comprise as much as 17 percent of the rock. They are chiefly anhedral to subhedral in shape, but some occur as euhedral phenocrysts.

Andalusite as prismatic aggregates comprises 24 percent of the dacite in the Richfield Oil Corporation ''Tulare Community'' No. 1 well, sec. 33, T. 19 S., R. 24 E., M. D.

The accessory minerals in order of abundance are as follows: magnetite, pyrite, zircon, apatite, titanite, succinite(?), hematite, ilmenite, garnet, and gold. The first five minerals mentioned are the most common and occur as they do in the plutonic rocks described above. Succinite(?), a hydrocarbon, was noted in samples from the Edison area. Hematite, ilmenite, and garnet are rare.

Gold was found in minute amounts in the sample from the Pacific Western Oil Corporation ''Greenlee'' No. 1 well, sec. 25, T. 19 N., R. 2 E., M. D. It probably was deposited by later mineralizing solutions.

The hypabyssal intrusives range from relatively fresh rocks to severely altered schists, the classification of which is doubtful. The more highly altered material will be described in a later section, and only those rocks which can be classified are considered here. Epidote, chlorite, and clinozoisite are always present as alteration products of the amphiboles and pyroxenes. Epidote and clinozoisite form anhedral to euhedral grains in veinlets or disseminated throughout the rock. Chlorite is nearly always interstitial and seems to attack both salic and femic minerals. It appears as an alteration product of devitrified glass in the andesites. It locally becomes pennine, especially when associated with biotite. Albite occurs as untwinned anhedral grains. Calcite appears as an alteration

product of the feldspars and as veinlets, in some cases associated with secondary quartz. Sericite, paragonite, and kaolin coat the feldspars. There are a few traces of limonite and leucoxene. Chalcedony occurs in veinlets. The fresh rocks exhibit no recrystallization and few alteration minerals are present. The great majority of the hypabyssal intrusives, however, are recrystallized and contain common to abundant alteration minerals. Some possess incipient schistosity.

Distribution and Relationship of Hypabyssal Intrusives

Hypabyssal intrusives are known to be widespread in the southern San Joaquin Valley, where they have been found in many wells. To the north, their extent is unknown because drilling has been scattered, but they have been found at intervals as far north as Oroville, in Butte County. They are grouped geographically as follows: (1) Oroville, Butte County; (2) Sacramento, Sacramento County; (3) Chowchilla, Madera County; (4) Tulare, Tulare County; (5) Pixley, Tulare County; (6) Poso Creek area, Kern County; (7) Bakersfield area, Kern County; (8) Edison-Mountain View area, Kern County.

Oroville, Butte County. The Pacific Western Oil Corporation ''Greenlee'' No. 1 well, sec. 25, T. 19 N., R. 2 E., M. D., west of Oroville, encountered a diorite porphyry. It is a fresh rock which may represent a peripheral intrusion associated with the Sierra Nevada orogeny.

Sacramento, Sacramento County. The Independent Exploration Company ''Unit Plan'' No. 1 well, sec. 19, T. 7 N., R. 6 E., M. D., a few miles southeast of Sacramento, found a very fine-grained porphyritic rock classified as an andesite. It has been fractured and mineralized, but is otherwise relatively fresh. The age and extent of the body is unknown.

Chowchilla, Madera County. A fresh malchite was cored in the Pure Oil Company ''Chowchilla'' No. 1 well, sec. 7, T. 10 S., R. 14 E., M. D., approximately 12 miles west of Chowchilla. The age and form of the intrusion are unknown, but the degree of alteration suggests an affinity to the Sierra Nevada intrusions.

Tulare, Tulare County. The Richfield Oil Corporation ''Tulare Community'' No. 1 well, sec. 33, T. 19 S., R. 24 E., M. D., bottomed in a fine-grained intrusive rock, which from its composition and the presence of glass in the groundmass was classified as a dacite. It is a relatively fresh rock, which may represent a somewhat shallower-seated intrusive, related in age to the Sierra Nevada batholith.

Pixley, Tulare County. An altered malchite was found in the Continental Oil Company ''Pixley Community'' No. 1 well, sec. 9, T. 23 S., R. 25 E., M. D. It exhibits considerable veining, and recrystallization of the minerals. The extent of the intrusive body is not known, but the degree of alteration together with the geographical position west of the Terra Bella meta-sediments, indicate that it may be pre-Sierra Nevada in age.

Poso Creek, Kern County. A small body of andesite, at least 2 miles in length, is located immediately south of Poso Creek, north of the city of Bakersfield. It is probably a relatively shallow-seated intrusion. One sample from this body obtained in the Standard Oil Company ''Fee'' No. 42-9 well, sec. 9, T. 28 S., R. 27 E., M. D., at a depth of 6209 feet, is a fresh, very fine-grained porphyry. A similar porphyry was cored in the Standard Oil Company No. 34-5 well, sec. 5, T. 28 S., R. 27 E., M. D., at

a depth of 7185 feet. This latter rock may have been glassy in part, as the groundmass is low in plagioclase and now consists mainly of chlorite. This intrusion is thought to be related in age to the Sierra Nevada batholith.

Bakersfield Area, Kern County. The Bakersfield area, which is primarily a quartz diorite province, contains numerous small intrusions of diorite aplite and malchite, encountered in wells at depths from 3475 feet to 10,589 feet. These rocks, with few exceptions, are fresh, and show only minor alteration, and some mineralization by calcite and chalcedony. They are probably dikes or similar intrusions in the quartz diorite, and thus are related to the later stages of the Sierra Nevada magma.

The Texas Company "Camp-West-Lowe" No. 1 well, sec. 7, T. 29 S., R. 27 E., M. D., and the Western Gulf Oil Company "K.C.L." No. B-45 well, sec. 22, T. 29 S., R. 27 E., M. D., cored altered malchites. These wells are near the Meridian Oil Company "Meridian Fee" No. 2 well, sec. 23, T. 29 S., R. 27 E., M. D., which encountered a highly altered fine-grained rock of igneous origin. The altered nature of these rocks, together with their geographical position on the western edge of the Bakersfield area, suggest that they belong to a single intrusion which antedates the Sierra Nevada batholith and may be related to the Edison-Mountain View intrusions mentioned below.

Edison-Mountain View Area. The hypabyssal intrusives of the Edison-Mountain View area form a belt several miles wide, which extends along the western side of the area between the towns of Edison and Arvin. These intrusives probably form a single body. Along their eastern edge, near Edison, they are most highly metamorphosed and are called the Dougherty schist; many are described as altered igneous rocks. This high degree of metamorphism is probably a result of proximity to the Sierra Nevada quartz diorite, as it diminishes toward the west throughout the Edison-Mountain View area. A study of the Dougherty schist, which will be dealt with in detail in another section, indicates that it intrudes the older sedimentary schists of the Edison area. All the hypabyssal intrusives of the Edison-Mountain View area are altered to a greater or less degree to epidote, clinozoisite, and chlorite. It is, therefore, thought that these intrusives are older than the Sierra Nevada intrusion.

A few wells in the Edison-Mountain View area encountered fresh, fine-grained porphyries which have been classified as andesites. The most notable of these andesites was recovered from the L. C. Morton "Jewett" No. 1 well, sec. 23, T. 31 S., R. 29 E., M. D. It is an unaltered porphyry possessing large, well-developed phenocrysts in a very fine-grained groundmass. The absence or low degree of metamorphism in these rocks indicates that they are small intrusives of Sierra Nevada age.

THE METAMORPHIC ROCKS

Serpentine-Bearing Rocks

The northernmost metamorphic sample studied came from the Texas Company "Jelly Bend" No. 18-8 well, at a depth of 7116 feet. This well is located in sec. 8, T. 29 N., R. 2 W., M. D., near Battle Creek, between the cities of Red Bluff and Redding in the upper Sacramento Valley. The core sample is mottled olive green and dark gray, massive, felsitic, and lacks evidence of structure. Under the microscope the texture is seen to be fine grained and schistose. The sample is composed of serpentine (85

percent), and auxilliary veinlets of chalcedony (pl. 17*A*). A very small amount of biotite (unoriented), magnetite, pyrite, and hematite is present.

About 50 miles to the south, the Richfield Oil Corporation ''Chico'' No. 1 well, sec. 17, T. 21 N., R. 1 E., M. D., at a depth of 6997 feet, cored into a dark, green to grayish-green massive altered rock. In thin section, it appears to have been a diorite porphyry, which was later heavily invaded by serpentine. It is slightly schistose and altered. The essential minerals are bronzite, oligoclase, biotite, and hornblende. Secondary minerals are serpentine, pennine and chlorite, clinozoisite, epidote, kaolin, paragonite, and leucoxene. The accessories are ilmenite, zircon, and titanite.

The presence of serpentine in these two widely spaced samples from the northern part of the Sacramento Valley suggests that autometamorphism may be more widespread below the sediments in this area than has been shown to date by the sparse well drilling. Diller [4] describes a serpentine outcrop, in the northwest corner of the Redding quadrangle, a part of a large area lying beyond the boundary, about the heads of Slate and Shotgun Creeks. He states:

> "The serpentine penetrates all of the adjoining rocks of the Redding quadrangle, showing that it is at least younger than the early Carboniferous. It is supposed to be of late Mesozoic eruption, in connection with many other similar masses in the Coast Range."

Both the Texas Company and Richfield Oil Corporation basement samples were found below Chico (upper Cretaceous) beds.

Farther south, near Stockton, the Richfield Oil Corporation ''Stockton'' No. 2 well, sec. 6, T. 1 N., R. 9 E., M. D., entered quartzite at 6368 feet. This rock is very hard, as a result of cementation and recrystallization: recrystallized quartz is coated and mortared by limonite. There are scattered grains of monazite, clinozoisite, and epidote. This highly indurated sediment was found below a series of continental Cretaceous beds, which are older than lower Panoche (upper Cretaceous).

The next metamorphic sample was taken from the Union Oil Company ''Floto'' No. 1 well to the south (sec. 5, T. 11 S., R. 18 E., M. D.) at a depth of 2660 feet. This is a weathered, mottled, dull olive-green and gray, fine-grained, schistose rock. In thin section it is seen to be a serpentinized, biotite-quartz schist with chlorite. Green biotite is very prominent in flakes and irregular aggregates. The quartz grains form a mosaic which has been broken by mineralization. Chlorite has formed from the biotite. The rock has been invaded heavily by serpentine carrying many minute fragments of the above minerals. There is some parallel arrangement of the biotite, quartz, and chlorite, indicating schistosity.

Metamorphic Rocks of the Terra Bella Region

Fine-grained, lead-gray to light greenish-gray, dull to lustrous schists have been encountered in a number of wells drilled between the towns of Traver and Ducor. They form a province having a length of about 60 miles and an average width of 20 miles. They are derived from clays and fine silts, most of which were carbonaceous.

Rock Types. The following rock types and names given are based on the mineral content of the rock, over 10 percent of the volume, arranged in decreasing amounts. Significant minerals of less quantity are also noted; for example, ''with biotite'' or ''with graphite''.

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[4] Diller, J. S., Description of the Redding quadrangle: U. S. Geol. Survey, Geol. Atlas, Redding folio (no. 138), p. 9, 1906.

1. Quartz-mica-graphite schist.
2. Graphite-quartz-mica schist.
3. Quartz-graphite schist with biotite.
4. Siderite(?)-mica-quartz-chlorite schist.
5. Quartz-biotite schist with muscovite.
6. Altered tuff (?) (predominance of chalcedony 95 percent).
7. Biotite-quartz-muscovite schist with graphite.
8. Metamorphosed igneous rocks.
   a. Aplite(?).
   b. Diabase.

Most of the rocks in the province are quartz-mica-graphite schists, with these essential minerals present in varying amounts. Quartz and recrystallized quartz predominate in most cases. The graphite occurs as fine, dust-like grains to sooty aggregates. Sericite and muscovite are usually fine and oriented along the lines of schistosity. Biotite, when present, is pale brown or green and may lie at various angles to the direction of schistosity. Schistosity is poor to fairly well developed and parallels the bedding of the original sediment.

South of Terra Bella, biotite-quartz-muscovite schists with graphite were found in the Tannehill Oil Company ''Tannehill'' No. 1 well in sec. 22, T. 23 S., R. 27 E., M. D., and the Tannehill ''Hunsaker'' No. 1 well in sec. 17 of the same township. Biotite comprises up to one half of the samples. It shows both yellow to brown, and yellow to dark-green pleochroism, and is oriented parallel to the direction of schistosity. A few muscovite metacrysts were found at an angle to the schistosity.

A dual-colored biotite was noted by Durrell[5] in some of the quartz-poor mica schists of the Lemon Cove schist.

The biotite-rich schists are on the eastern edge of the Terra Bella metamorphic province. A gradual increase in biotite was noted in well samples approaching this area. Likewise, there is an increase of white mica, with a larger and better development of the crystals.

The gray, thinly laminated, quartz-mica-graphite schists are often called ''slates'' in core descriptions; however, they lack slaty cleavage and the hardness of true slates, as described by Tyrrell.[6] The term schist is preferred for the bulk of these rocks. A few, rich in sericite, can be classified as phyllites. Those samples weakly metamorphosed are considered argillites or shales.

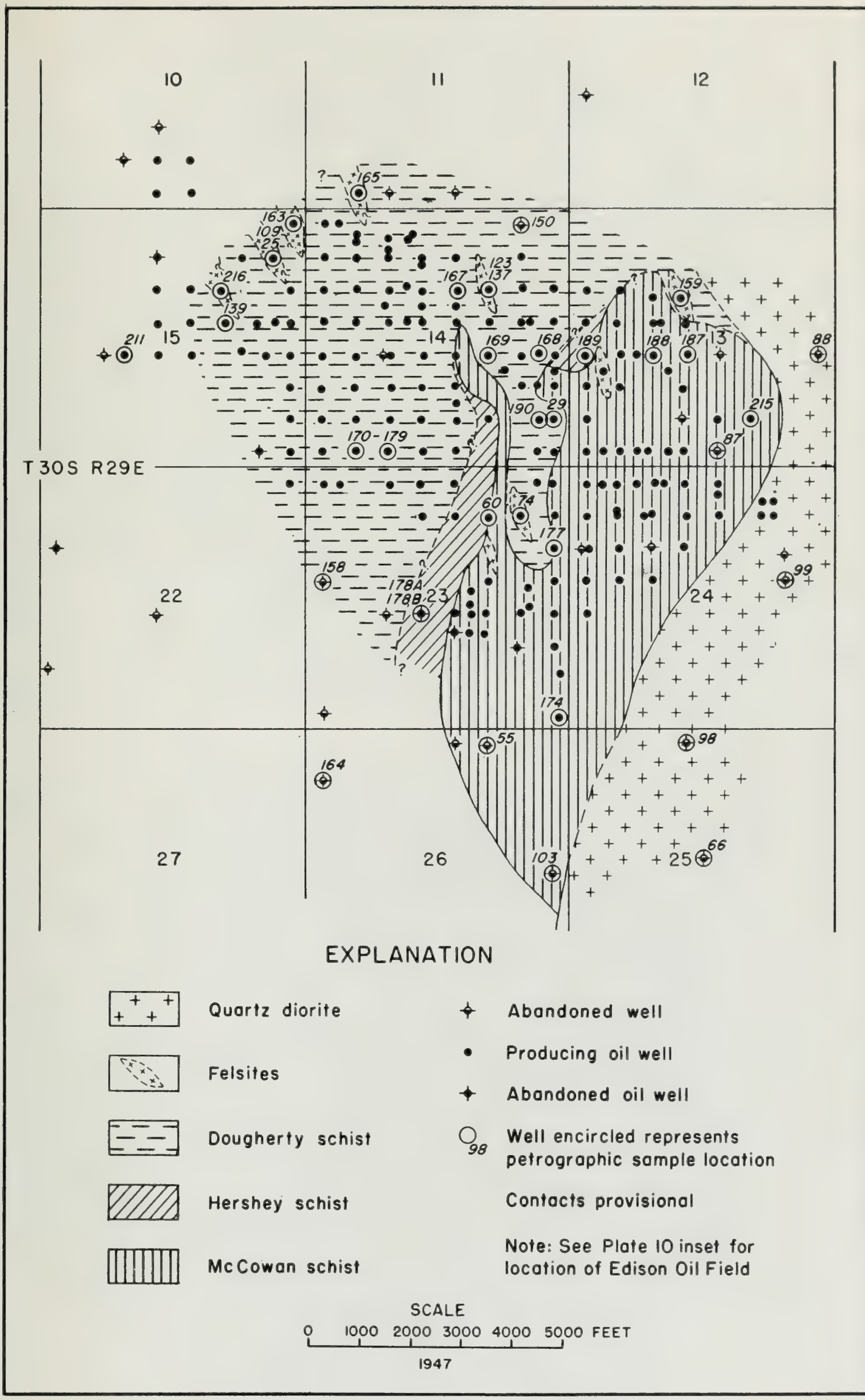
About 6 miles northwest of the town of Terra Bella, two wells encountered metamorphosed igneous rock. The wells are several miles apart, and they are nearly surrounded by wells which found the more common quartz-mica-graphite schist. The metamorphosed igneous rocks represent intrusions into the surrounding rock. It is possible that they were connected. These intrusives will be more fully described later.

The Amerada Petroleum Corporation ''Lawton'' No. 58-26 well, sec. 26, T. 17 S., R. 19 E., M. D., 2 miles south of the town of Riverdale, cored into a dark-gray to bluish-gray hard shale, at a depth of 11,790 feet. Fine siltstone laminae showed a dip of 58 degrees. This shale is slightly metamorphosed. The lithology and the steep attitude of the bedding suggest that the rock is older than the oldest known Cretaceous (Panoche-Upper Cretaceous) of the area, and probably related to the quartz-mica-graphite schists of the Terra Bella region.[7]

[5] Durrell, Cordell, Metamorphism in the southern Sierra Nevada northeast of Visalia, California: Univ. California Dept. Geol. Sci. Bull., vol. 25, p. 53, 1940.

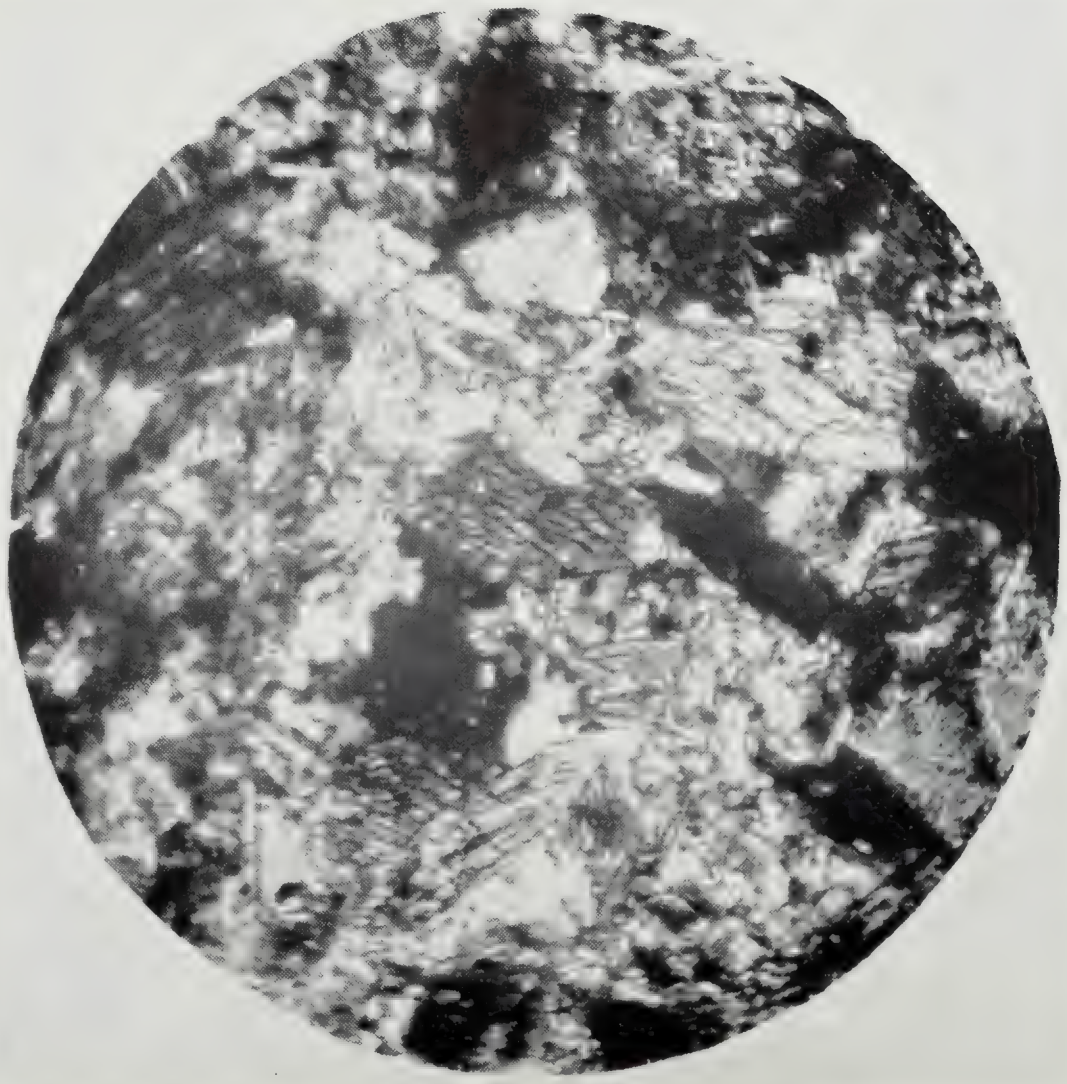
[6] Tyrrell, G. W., The principles of petrology, 2d. ed., p. 283, 1930.

[7] Later information from the Amerada Petroleum Corporation reveals the presence of pyritized megafossils in the cored material at 11,989 feet, which have been identified questionably by Dr. Paul Goudkoff as *Pseudomonotis*. This genera is characteristic of the Triassic.



BASEMENT ROCKS OF THE EDISON OIL FIELD

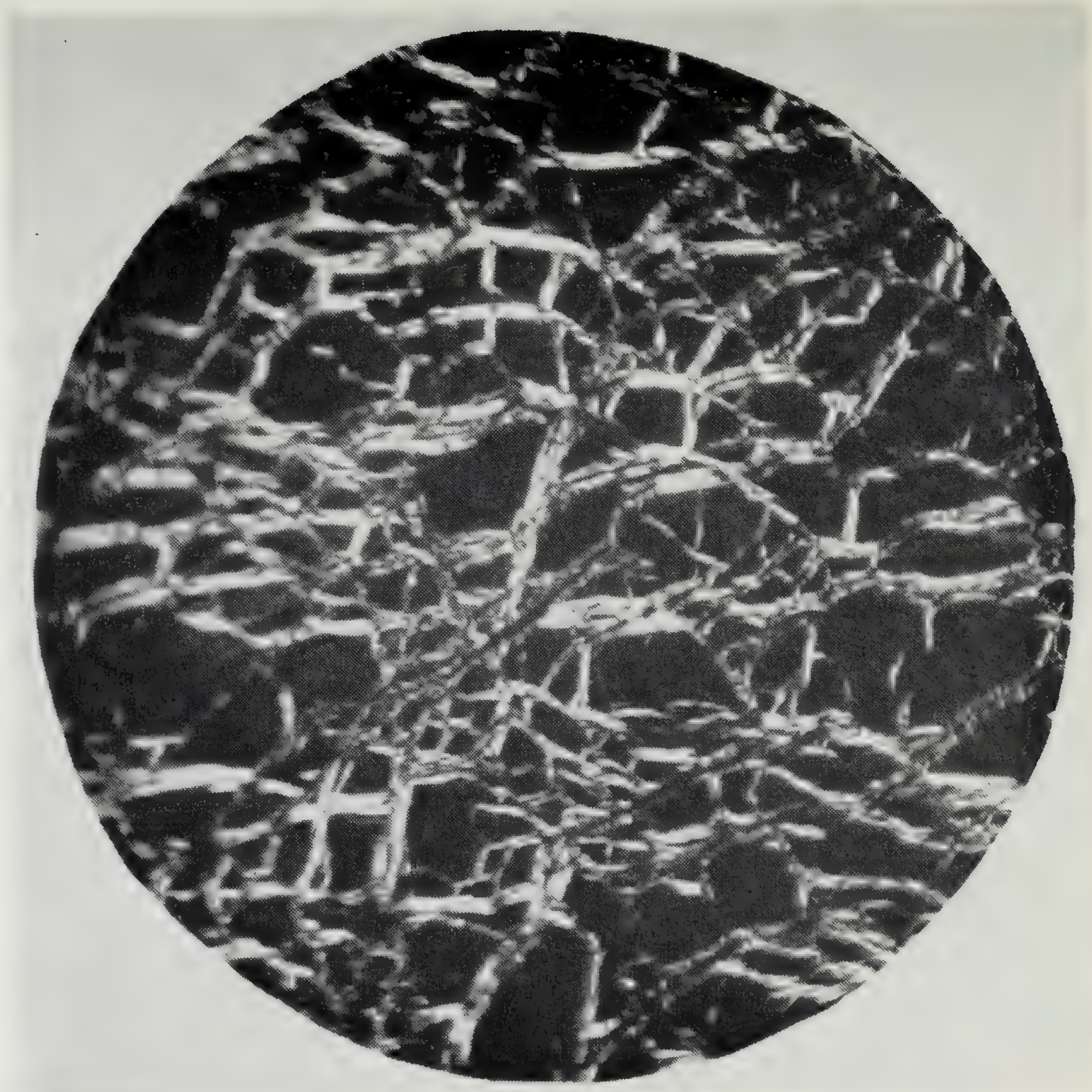
3—81650



PHOTOGRAPHS OF TYPICAL BASEMENT ROCKS

A, HORNBLENDITE
Slide No. 166. Field is almost entirely hornblende. Note amphibole cleavage. Crossed nicols. x54.

B, GABBRO
Slide No. 147. Field shows laths of bytownite (twinned), ophitically surrounded by augite. Crossed nicols. x15.



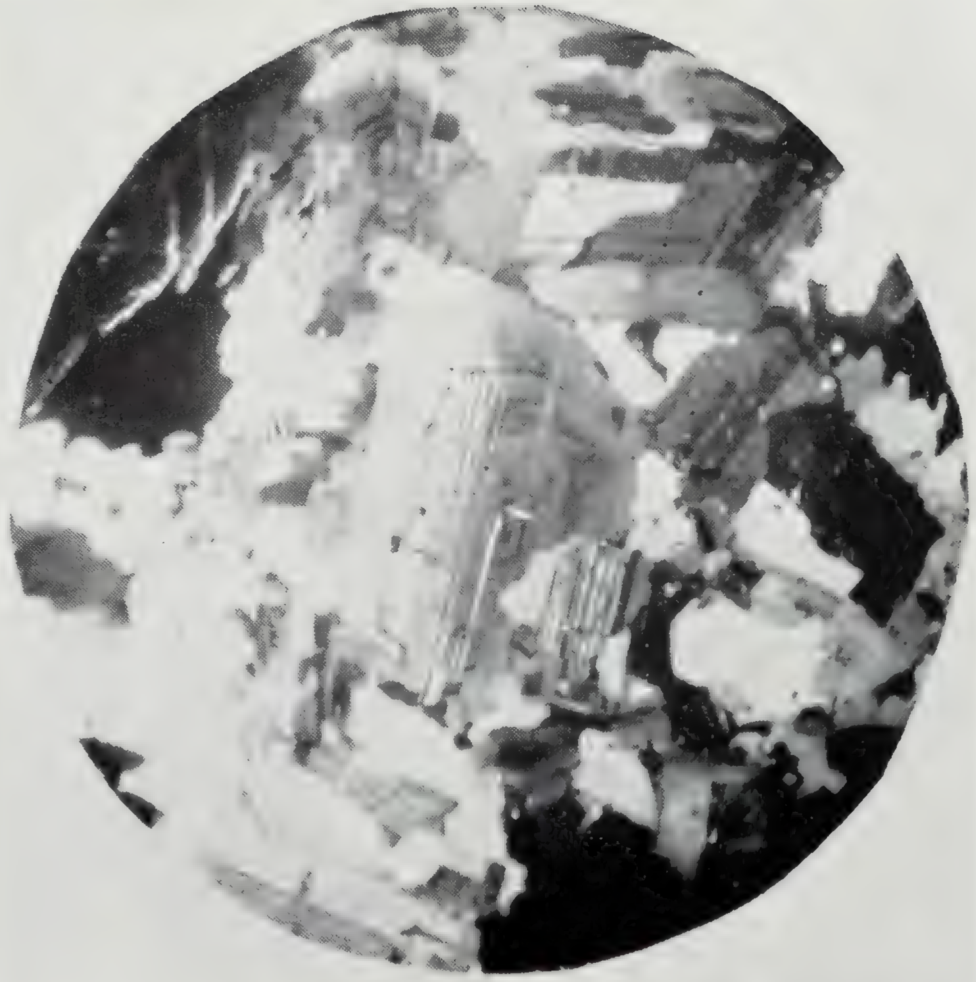
PHOTOGRAPHS OF TYPICAL BASEMENT ROCKS

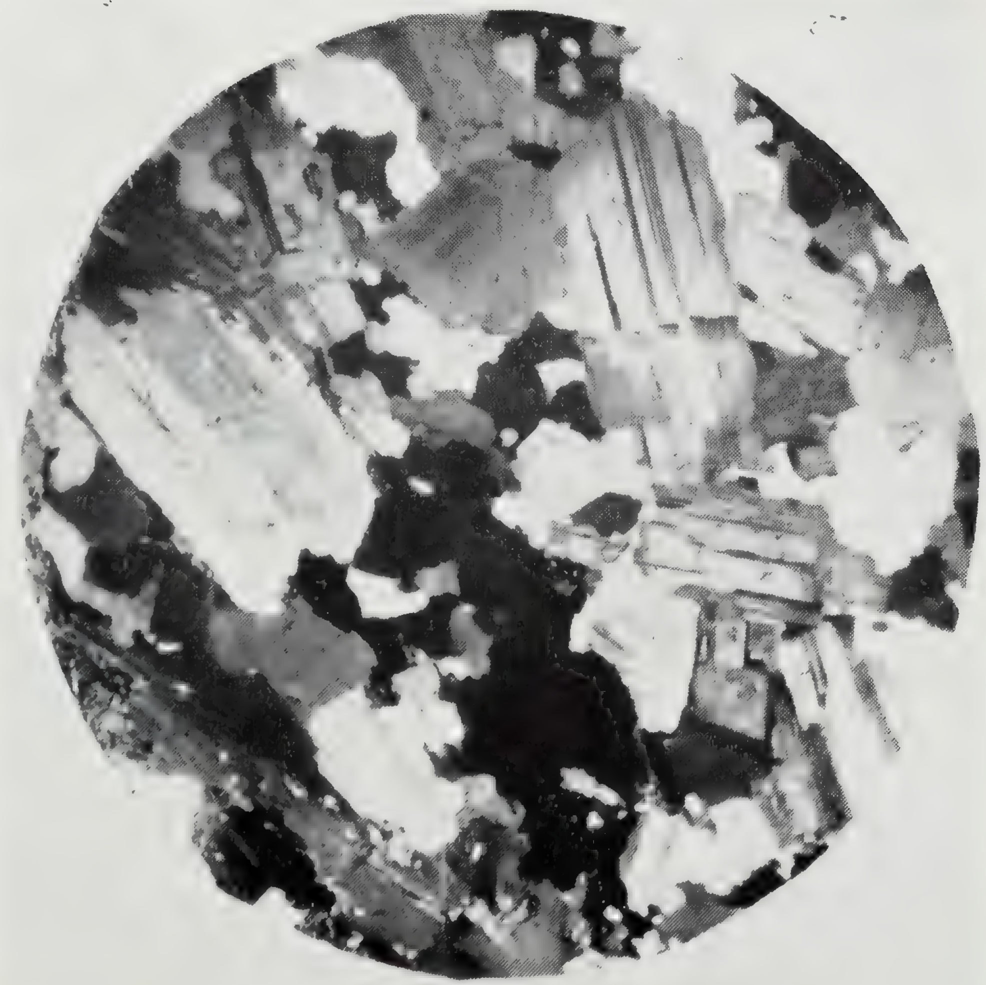
A, DIABASE

Slide No. 64. Field shows long lath-shaped labradorite crystals (twinned) surrounded by hornblende and augite. Crossed nicols. x54.

B, TACHYLYTE

Slide No. 52. Field shows basaltic glass, minutely fractured and veined by chalcedony. Crossed nicols. x54.





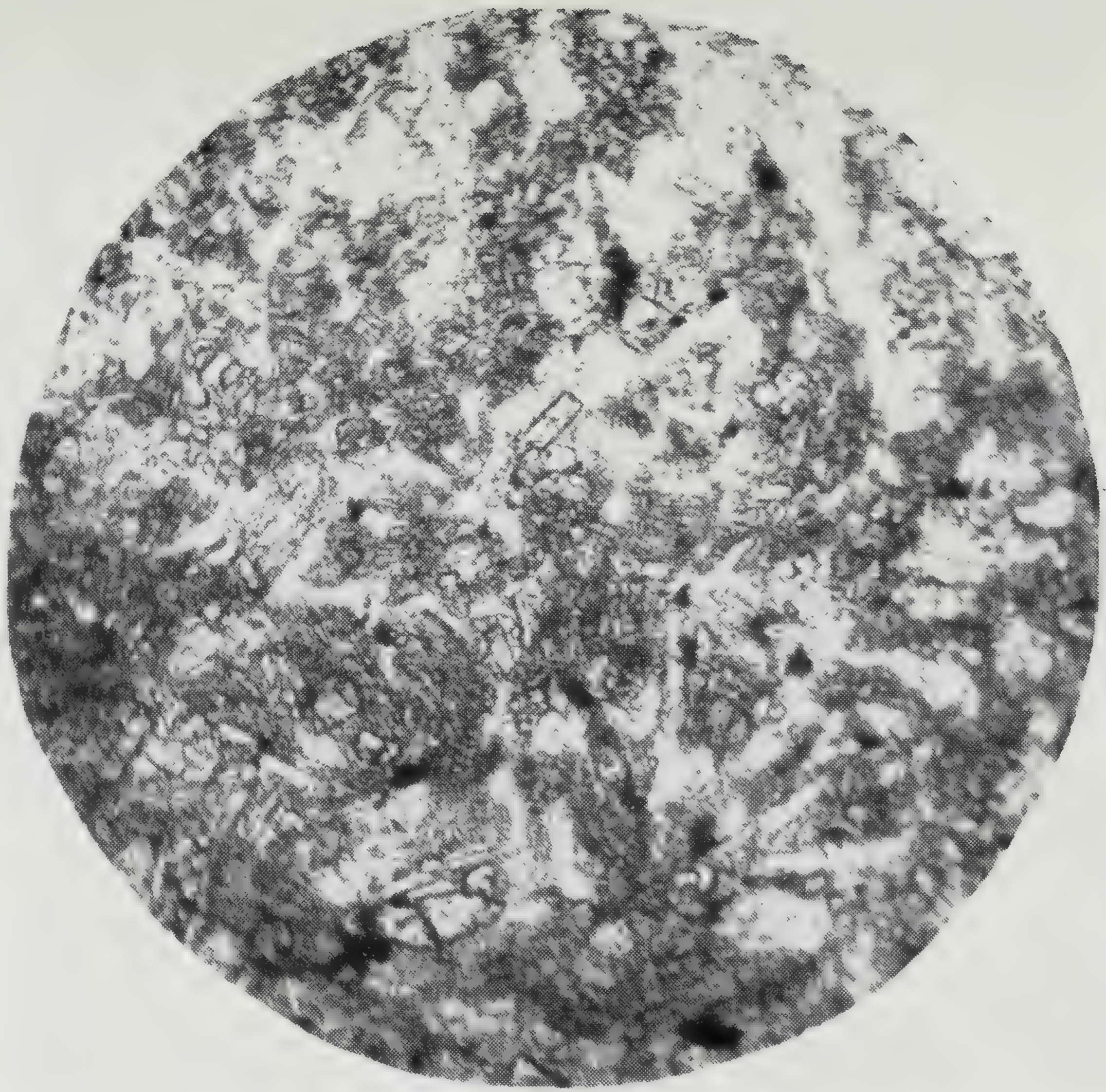
PHOTOGRAPHS OF TYPICAL BASEMENT ROCKS

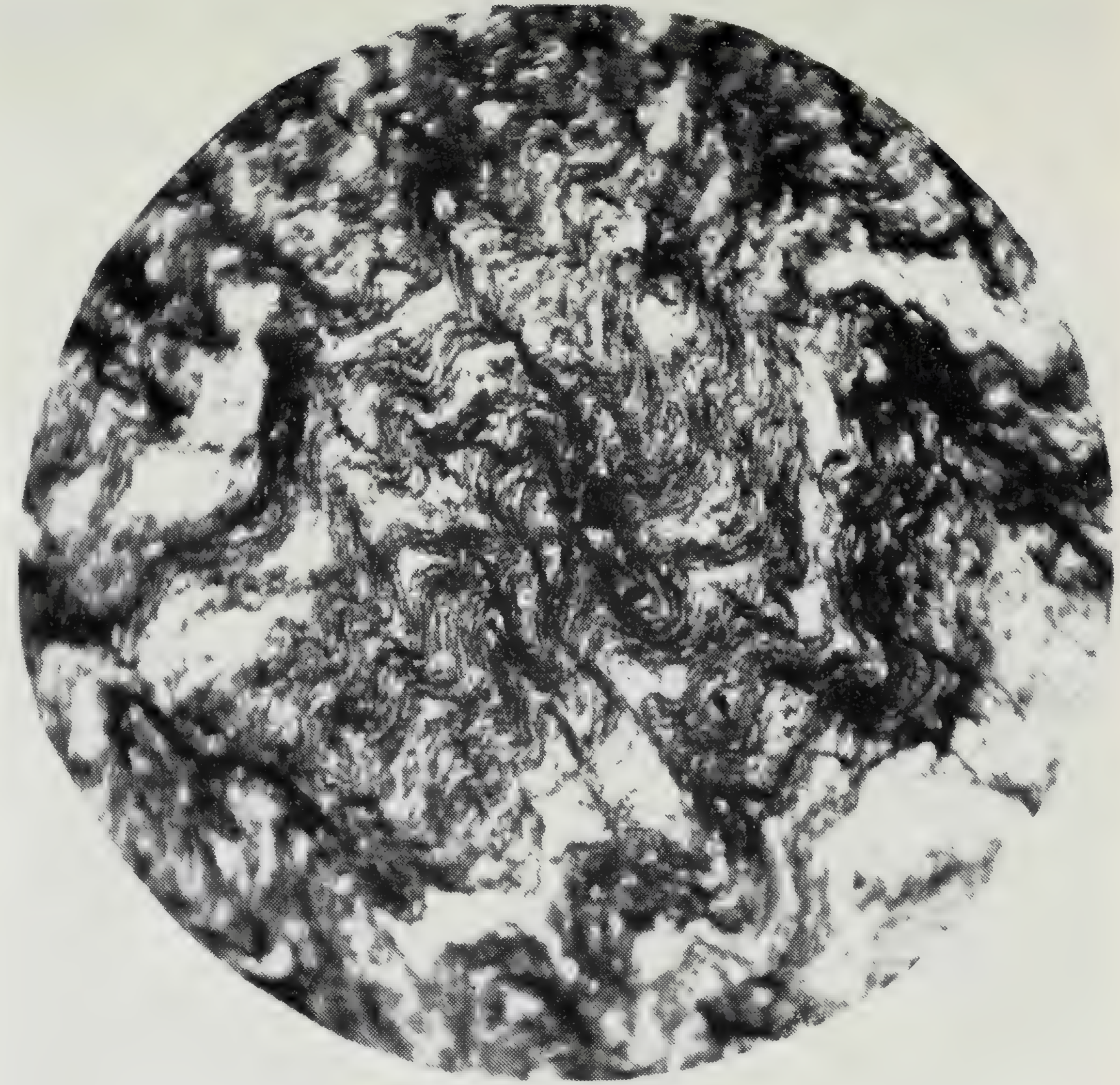
A, QUARTZ DIORITE

Slide No. 8. Field shows prominently zoned and twinned andesine crystals associated with orthoclase (dull gray, untwinned), quartz (white), biotite (black). Crossed nicols. x15.

B, GRANODIORITE

Slide No. 155. Field includes polysynthetically twinned, faintly zoned andesine crystals associated with biotite (black and dark gray), orthoclase (medium gray), and quartz (white). Crossed nicols. x15.





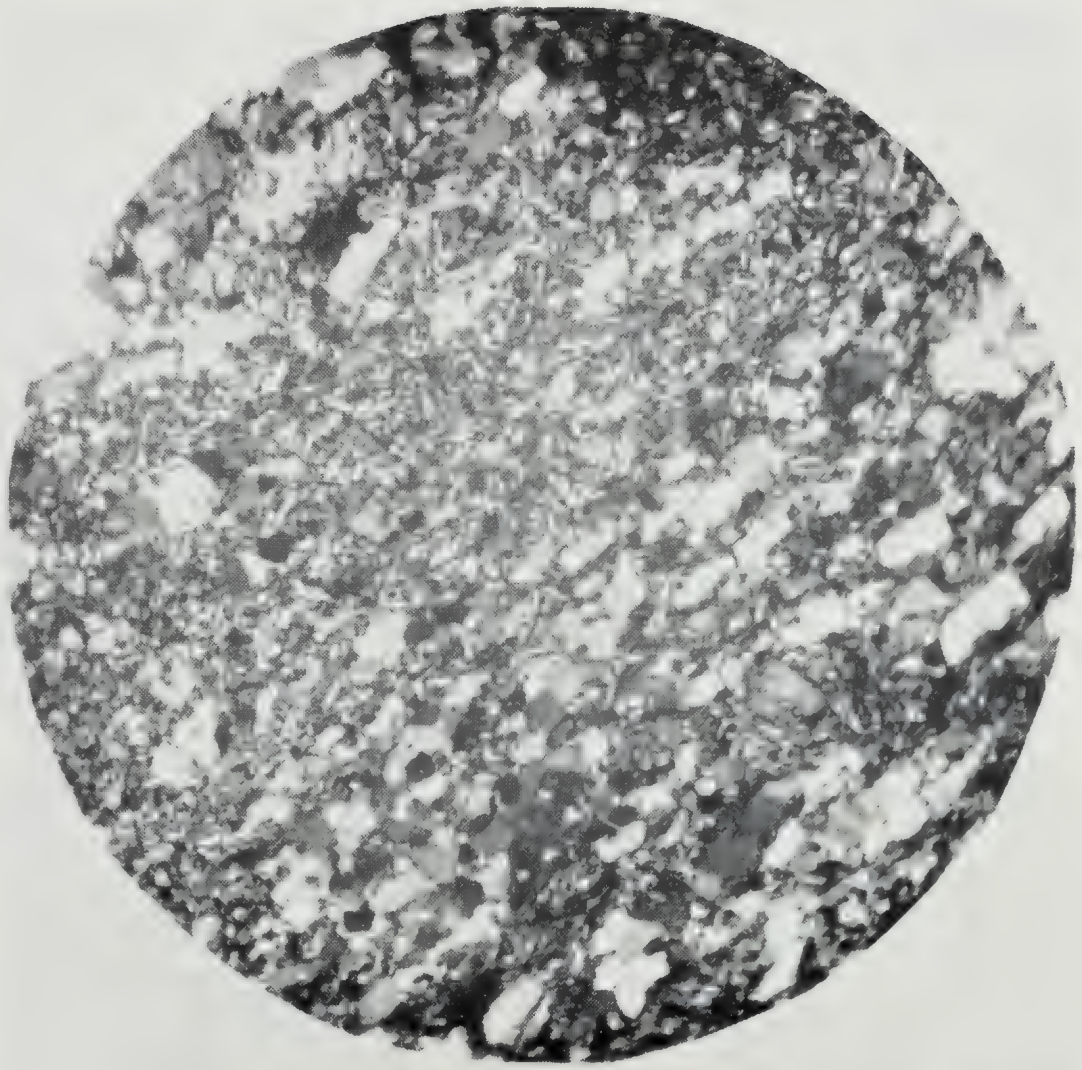
PHOTOGRAPHS OF TYPICAL BASEMENT ROCKS

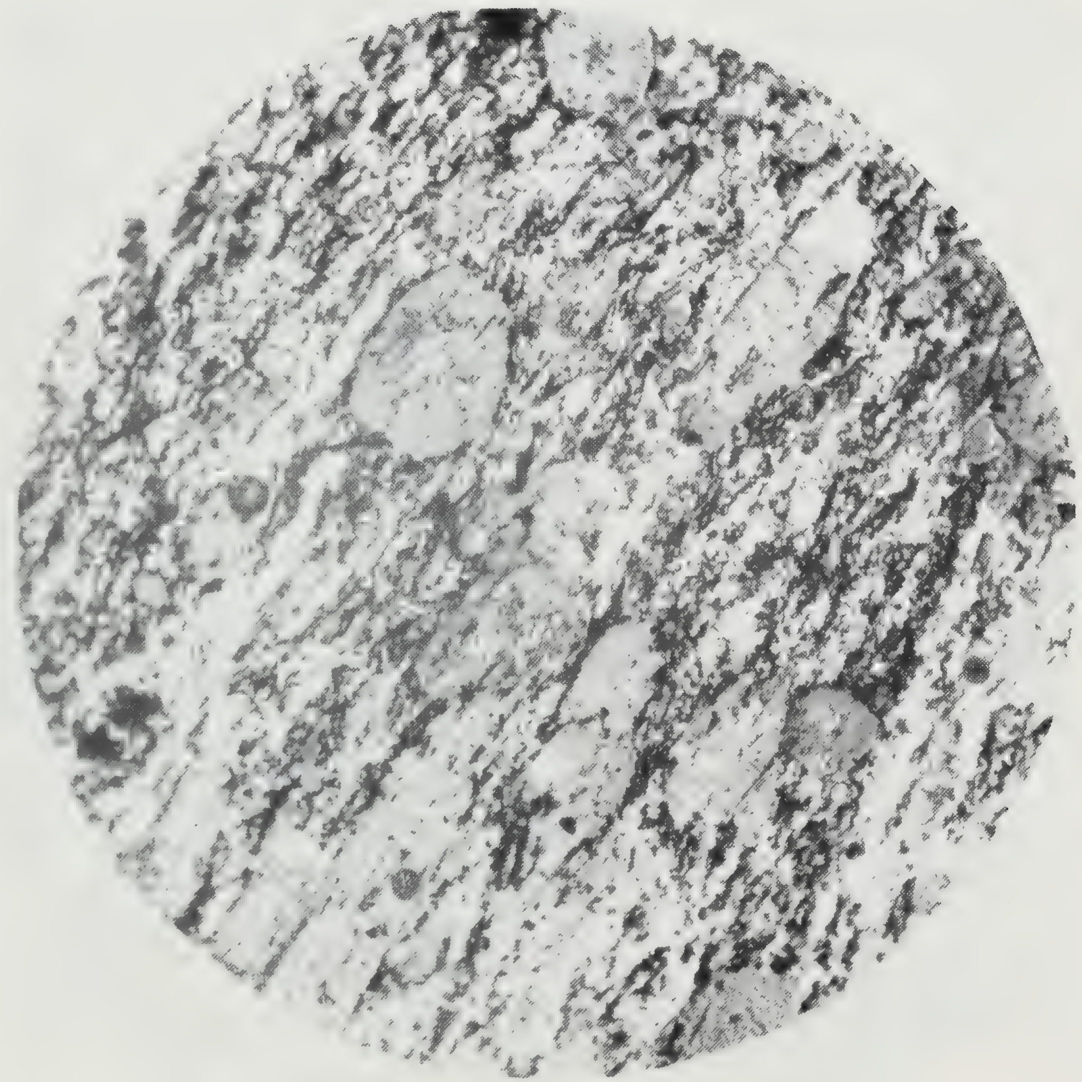
A, DIORITE APLITE

Slide No. 163. In "Dougherty" schist. Field shows abundant epidote and clinozoisite crystals (high relief) surrounded by matrix of small andesine laths (light gray) and anhedral hornblende (dark gray). Plane polarized light. x54.

B, "McCOWAN" SCHIST

Slide No. 188. Quartz-graphite-muscovite schist with biotite. Banding caused by alternating layers of recrystallized quartz and graphite with mica. Shows good development of false cleavage. Plane polarized light. x54.

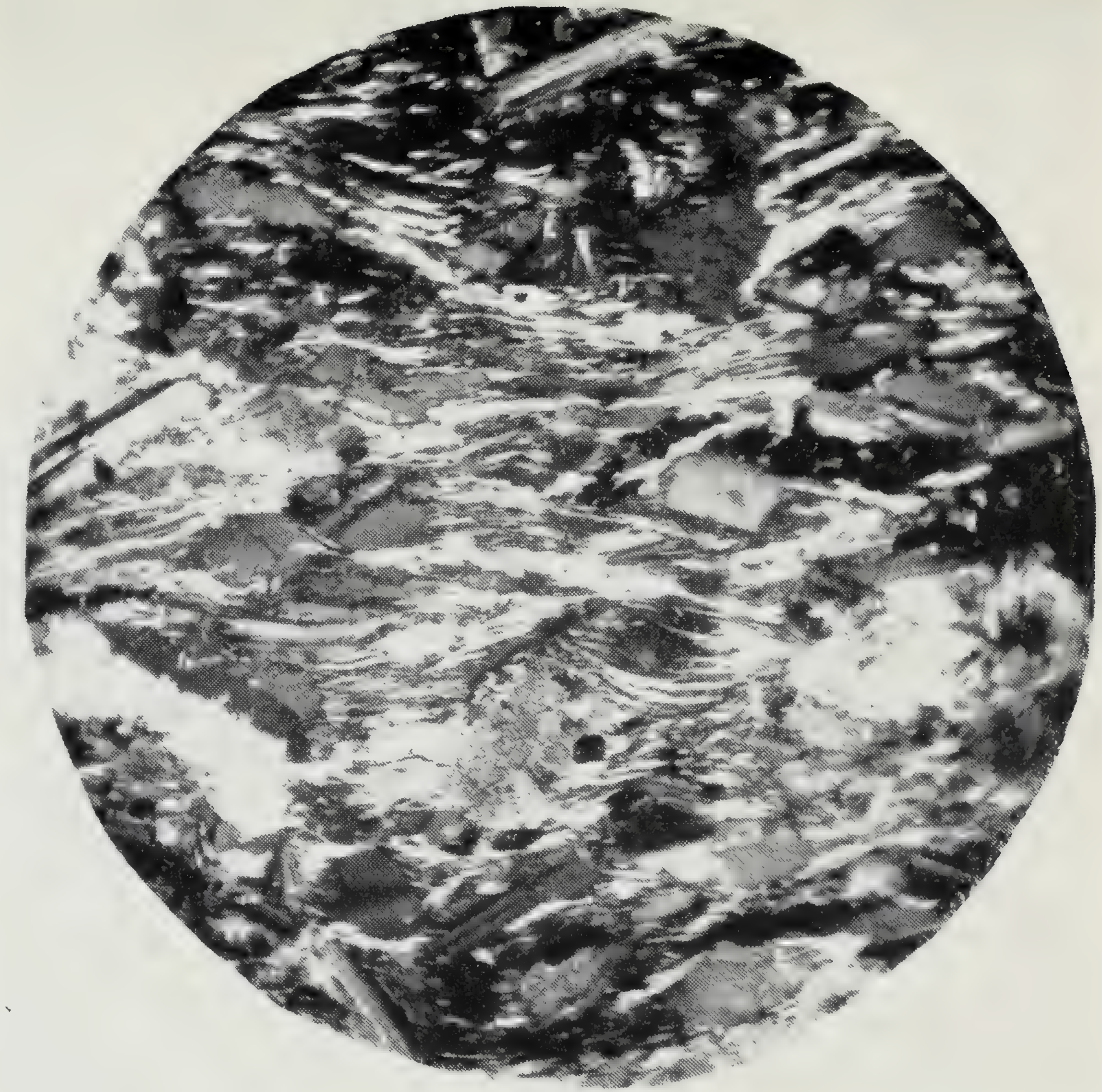




PHOTOGRAPHS OF TYPICAL BASEMENT ROCKS

A, "HERSHEY" SCHIST
Slide No. 178A. Quartz-epidote schist with biotite. Quartz recrystallized, forming a mosaic with epidote (small grains, high relief) and a little biotite (black). Crossed nicols. x54.

B, QUARTZ-TOURMALINE-GRAPHITE-BIOTITE SCHIST
Slide No. 185. Similar to "McCowan" schist; shows marked development of stout tourmaline (light gray) metacrysts parallel to schistosity. Plane polarized light. x87.



PHOTOGRAPHS OF TYPICAL BASEMENT ROCKS

A, SERPENTINE

Slide No. 181. Field entirely serpentine composed of a mixture of antigorite and chrysotile fibres. Crossed nicols, x54.

B, META-DIABASE

Slide No. 77. Field composed of labradorite laths (gray) and ragged hornblende (light gray). Original ophitic texture is present. Shreds of hornblende flow around the blocky crystals with a tendency to orient along the lines of schistosity. Crossed nicols. x54.

About 6 miles northwest of Terra Bella, the Tide Water Associated Oil Company "Core Hole" No. 87-11, in sec. 11, T. 22 S., R. 26 E., M. D., cored into a dark-green to grayish-green massive schist. In thin section, the rock appears to be derived from an aplite. Fair schistosity is developed and numerous quartz veinlets run through the slice. The sample consists mostly of chlorite (and some pennine). Andesine is prominent, but highly altered. Many flakes of paragonite are within and surrounding the andesine grains. Some of the andesines still show zoning. Hornblende and biotite exist as traces. Leucoxene (after ilmenite(?)) is common.

In section 15 of the same township, the Turner "Glaze" No. 1 well cored a dark, greenish-gray, metamorphosed diabase basement at a depth of 3279 feet. Under the microscope, the rock exhibits a certain degree of schistosity, although the original ophitic texture can be recognized. The feldspar is labradorite and shows strain shadows, bending, and fracturing. Hornblende is prominent, and often shows ragged edges, where shredding has taken place. These shreds and slivers have recrystallized around the larger, blocky minerals giving the impression of flowage (pl. 17*B*).

The tongue-shaped quartz diorite below the Tertiary mantle in the old Terra Bella oil field has been described previously. It is quite fresh, and intrusive into the graphite-bearing quartz-mica schist. The unmetamorphosed character of the quartz diorite indicates a later age than the adjacent Terra Bella metamorphics.

The Richfield Oil Corporation "Terra Bella Adams" No. 1 core hole in sec. 29, T. 22 S., R. 27 E., M. D., encountered an altered tuff(?) at a depth of 1912 feet. A specimen of this core is composed of glass, with a very small amount of quartz and orthoclase.

Nature Before Metamorphism. The presence of the original bedded structure and mineral assemblage indicates that the rocks of the Terra Bella region were derived from clay and fine silt. They were no doubt carbonaceous, as shown by the prevalence of graphite in the samples. The absence of coarser clastics, and the thinly laminar structure, suggest that deposition was slow and rhythmical. Pyroclastic material is rare, having been found in only one sample.

The small area of meta-igneous rock northwest of Terra Bella is a component of the igneous activity in the southern San Joaquin Valley, which followed the deposition of the sediments. This igneous activity was earlier than that which intruded the prominent quartz diorite of the Sierra Nevada batholith.

Nature of Metamorphism. The schist samples of the Terra Bella region belong to the epizone of regional metamorphism. Their degree of metamorphism ranges from very low near the center of the Valley, to dynamothermal approaching the Sierra Nevada. This is shown by the increasing and better development of biotite and muscovite in this direction. Likewise, schistosity is more pronounced in samples from the east side of the province.

Comparison With the Kaweah Series. Samples of schists from the Terra Bella district were compared in the field with the Kaweah series named and described by Durrell.[8] No close correlation of the rocks could be made. The thin, graphitic-schist or phyllite interbeds in the Homer

[8] Durrell, Cordell, op. cit. pp. 13-16, and pp. 39-99.

quartzite bore the closest resemblance to the more common graphitic schists of the Terra Bella district. According to Durrell, the Kaweah series is very lenticular. Lenticularity and the distance separating the areas may explain the difficulty of correlation by this method.

The graphitic schists of Terra Bella resemble more closely certain facies of the Mariposa farther north. Their closest and best correlative is the "McCowan" schist at Edison.

Metamorphics Between Terra Bella and Edison

Between the metamorphics of Terra Bella and the Edison metamorphic province, a distance of about 50 miles, a number of scattered wells have drilled into schist basement. The schist occurrences are limited in size, the predominating rocks being various igneous intrusives. The schist patches are probably small erosional remnants of a once-continuous roof above these later igneous intrusives.

A brief description of the metamorphic rock found in the wells between Terra Bella and Edison is given in the order of approach to Edison.

The Shell Oil Company "K. C. L." No. 1 well (Corral Canyon), sec. 16, T. 26 S., R. 28 E., M. D., entered lead-gray schist at 1006 feet. It is a quartz-biotite-chlorite schist with graphite; composed mostly of recrystallized quartz; 15 percent biotite, partially oriented; and considerable chlorite and graphite. In a slide, the graphite and a minor amount of pyrite cause a sooty appearance. Schistosity is poorly developed.

A similar rock, somewhat coarser in grain, was cored in the A. Bruce Frame "Dominion" No. 1 well, sec. 18, T. 26 S., R. 28 E., M. D., several miles to the west, at a depth of 2476 feet. The predominating quartz is recrystallized. Biotite exists in lamellar aggregates. Chlorite is colorless to light green, and like biotite, is not oriented. Graphite or carbon is scattered like dust through the slide. From the appearance, metamorphism has been moderate. Due to its slightly coarser grain the effects of regional dynamic metamorphism may not be as noticeable as in the nearby derivatives of clays and fine silts.

In a "green schist" sample from the Shell Oil Company "K. C. L." No. A-58-8 well, sec. 8, T. 27 S., R. 26 E., M. D., depth 9279 feet, the schistosity planes have a rough 70-degree dip. Under the microscope, this rock was classified as a quartz-epidote schist of igneous origin. Nearly all of the hornblende has altered to epidote and clinozoisite. The feldspars are strained and fractured. Kaolin is prominent and masks most of the slide. Numerous veins of chalcedony are present.

About 11 miles southeast of the above well, Gene Reid's "Lorraine" No. 1, sec. 2, T. 28 S., R. 27 E., M. D., penetrated a hard, dark-gray to almost black schist with a 60-degree dip to the schistosity planes. This rock was classified as a hornblende-andesine schist derived from a fine-grained, igneous rock, possibly a malchite. Hornblende, with anhedral to subhedral shapes, makes up about half the slide. The feldspars are andesine (40 percent) and orthoclase (1 percent). The feldspars, with a small amount of quartz, form a generally recrystallized, mosaic-like matrix. The effect of the whole slide is granulose, in combination with incipient schistosity. The rock is close to an amphibolite.

On the east edge of the Fruitvale oil field, a light-gray, dense, felsic-appearing basement was cored in the Meridian Oil Company "Meridian Fee" No. 2 well, sec. 23, T. 29 S., R. 27 E., M. D., at 8530 feet. Under the

microscope, it presents a streaked, fine-grained groundmass composed of chlorite and kaolin, and larger chlorite pseudomorphs after aegirite and plagioclase. A small amount of hornblende is present. Introduced quartz veinlets contain a little calcite and traces of albite(?). Relict original texture indicates an igneous origin, probably a porphyry.

In the Ant Hill oil field, east of Bakersfield, the Amerada Petroleum Corporation "S.P." No. 2 well, sec. 15, T. 29 S., R. 29 E., penetrated a very dark, greenish to black, mottled basement rock. A sample taken at 4385 feet shows a fine-grained groundmass containing nearly equal amounts of recrystallized plagioclase and quartz, and a little orthoclase. This effects a mosaic with intergrowths of chlorite, an abundance of aegirite with a small amount of hornblende in the shape of lenticular grains, and actinolite in the shape of slender crystals and needles. The high percentage of plagioclase, with the possibility that more is present than can be recognized, leads to the conclusion that the rock was derived from a fine-grained igneous intrusive.

Basement Rocks of the Edison Oil Field and Vicinity

The Edison oil field in Kern County offers an opportunity for study of many types of basement rocks, below the sediments, because of the large number of wells drilled into the basement complex in search of oil.

The present geologic structure of the field, at basement depth, is a faulted dome-like fold. The south and west flanks are the most extensive; the north and east flanks are shortened by faulting, dropping the basement off rapidly. Some sort of a "high", though not as strong, undoubtedly has existed here for a very long period of time. It has influenced most of the Miocene and probably earlier deposition.

The edge of the Sierra Nevada batholith, composed of quartz diorite and associated igneous rocks, bounds the east edge of the oil field. It is a medium to coarse-grained, granitoid rock similar to the quartz diorites which form the southeastern rim of the San Joaquin Valley. The quartz diorite-schist contact must be very steep or faulted, for no wells first entering schists have passed through them into younger quartz diorite.

In well cores, the quartz diorite is slightly fractured, but not badly altered. Prospect wells so far have found it barren of oil; one well yielded fresh water on a formation test.

The following names for the Edison metamorphics have been drawn from local oil-producing lease names, to facilitate the description and classification of samples from the wells. Plate 10 shows the areal distribution of the rocks within the field.

"McCowan" Schist. Immediately west of the quartz diorite, a number of wells have drilled into lead-gray, fine-grained, laminar to rarely slaty, sectile to hard schists. Many of the samples show a satiny luster. Schistosity planes, for the most part original bedding planes, dip from 70 degrees to vertical.

These schists form a body, roughly lenticular in shape, nearly 2 miles long, and about 1 mile wide, elongated in a northward direction.

The greatest well penetration into this rock is 1436 feet; the greatest penetration measured with sidewall sample[9] control is 1337 feet. No well is known to have drilled through this series.

[9] A device used to take small formation samples from a bore-hole in a lateral direction, usually after the desired depth is reached by drilling.

Samples of "McCowan" schist are seen under the microscope to consist of fine-grained quartz-graphite-muscovite schist with biotite, quartz-muscovite-graphite-biotite schist, quartz-biotite-chlorite-muscovite-magnetite schist and biotite-quartz schist with chlorite. The structure is schistose; those samples containing a fair percentage of graphite exhibit false cleavage,[10] a characteristic of some argillaceous sediments which have been subjected to stress and a certain amount of pressure. This causes a crenulated appearance in the slide with minute folding in a parallel arrangement, and a small amount of microscopic shearing along the direction of the folding or false cleavage (pl. 15*B*). Some of the micas tend to be oriented in this direction.

The Jergins Oil Company "McCowan" No. 13 B-5 well, sec. 13, T. 30 S., R. 29 E., M. D., cored a typical-appearing, lead-gray, fine-grained schist. In thin sections, it is a fine breccia, composed of fragments of "McCowan" schist ranging from minute to 5 by 10 millimeters in size. There is a slight linear arrangement of the larger schist fragments, but the smaller chips show no tendency toward orientation. All of the fragments are mortared by veinlets of calcite, partly spherulitic. A restudy of the hand specimen shows schistosity with a prominent 70 degree dip. This has been unaffected by the brecciation and rotation of the fragments between the planes of schistosity. Calcite veinlets transgress the schistosity and cement the fragments. This indicates a period of severe mechanical stress after the deposition and metamorphism of the "McCowan" schist; followed by calcite mineralization.

The "McCowan" schists were no doubt thinly bedded carbonaceous clays and fine silts. They are considered the oldest of the Edison metamorphics.

"Hershey" Schist. A few wells have encountered very fine-grained, green to pistachio-green schists showing poor laminar structure, differing in appearance from the "McCowan" schist, but separable only with difficulty in the field and under the microscope from the adjacent "Dougherty" schist, which was derived from igneous rock. The "Hershey" schist may be of igneous origin, but if so, is derived from a more acidic magma than the "Dougherty" schist. Certain textural properties, and the predominance of quartz indicate a sedimentary origin (pl. 16*A*).

The nature of the contact of "Hershey" schist with the western edge of the "McCowan" schist is not known. Drilling has not defined the limits of the "Hershey" clearly. It is shown on the map as a narrow, discontinuous band along the west side of the "McCowan" schist, extending for about 1½ miles in a northeast direction. Several wells have gone through the "Hershey" schist, into "McCowan."

The "Hershey" schist is comprised of quartz-epidote schist with biotite, and heavily mineralized quartz schists. The quartz-epidote schist is fine grained and made up mostly of recrystallized quartz and some plagioclase, causing a mosaic-like texture. Secondary quartz forms rough knots and lenses parallel with the schistosity. Secondary albite is often associated with these quartz knots. Biotite is commonly oriented along the lines of schistosity; a few crystals, here and there, do not conform, but lie at various angles. Epidote is prominent and is accompanied by a small amount of clinozoisite. Traces of ilmenite, leucoxene, garnet, and apatite were found.

[10] Harker, A., Metamorphism, pp. 152-159, 1932.

"Dougherty" Schist. The west half of the basement producing area of the field is in "Dougherty" schist. The original igneous rocks were fine grained, probably malchites and diorite aplites. Relict texture and structure are present, and are sufficient to identify the original type (pl. 15*A*).

Dynamothermal metamorphism ranges from low, on northern and western flanks of the field, to quite pronounced near the center; the schistosity developed follows accordingly. In the E ½ sec. 14 and NE ¼ sec. 23, T. 30 S., R. 29 E., M. D., basement wells outline a "dike" of "Dougherty" schist derived from fine grained diorite and aplite, which intruded the "McCowan" and "Hershey" rocks. Metamorphism and alteration are most advanced in this area, and much of the character of the original igneous rock has disappeared.

The essential minerals in the schist are andesine feldspar and hornblende, hypersthene, aegirite, and augite, in order of decreasing amount. Biotite is quite common, and much of it may be secondary.

Minerals developed by metamorphism are epidote and clinozoisite, chlorite and pennine, tremolite, actinolite, biotite, quartz, albite, serpentine, paragonite, magnetite, and pyrite. Kaolin, from the feldspars, and leucoxene, from ilmenite, are alteration products. The epidotes are always present and prominent, sometimes comprising 40 percent of the specimen. Clinozoisite exhibits low bluish-gray birefringence in contrast with the highly birefringent epidote. Green and colorless chlorite has been found in all of the samples in amounts up to 30 percent. Pennine, a chlorite with an abnormal Berlin blue interference color, was found in the schists high in hornblende.

Serpentine is present in the chlorite-biotite schist found in the Jergins Oil Company "Hershey" No. 9 well, in sec. 14, T. 30 S., R. 29 E., M. D. This well is located close to the eastern margin of the "Dougherty" schist "dike."

The Jergins Oil Company "Dougherty" No. 5 well, in sec. 14, T. 30 S., R. 29 E., M. D., ended in a serpentinized, enstatite malchite(?) after penetrating a thin chlorite schist of igneous origin. Dynamothermal metamorphism has greatly altered the rock. Serpentine forms much of the groundmass, cementing grains of biotite, sericite, muscovite, quartz, and orthoclase. The quartz and orthoclase grains are fairly large, angular, broken, and scattered. Porphyroblasts of enstatite show strain; some of the serpentine appears to have been derived from their alteration. Calcite forms radial aggregates, several having small magnetite cores.

The occurrence of serpentine in these wells suggests that it is related to the contact of the early intrusives with the sediments.

Felsites. In coring the basement zone, operators have experienced difficulty recovering the "softer" or fractured rock which is probably the most oil productive. Sidewall sampling has been more successful. Coring may result in a few "nubbins" of hard, fresh-appearing igneous rock consisting of aplites and malchite, which have been altered to some extent, but not metamorphosed. Mineralogically, they are similar to the igneous rocks which later formed the "Dougherty" schist. They may be stringers or small dikes from the main mass having some physical or chemical reason to resist later metamorphism. It is possible that these fresher rocks are related to the Sierra Nevada intrusion. They are shown on the Edison map as segregations in the schist areas.

Nature of Metamorphism. The metamorphics of the Edison region fall within the same limits of regional metamorphism found at Terra Bella. The minerals and textures of the rocks are those of the epizone. More of the schists of Edison were derived from igneous rock; however, a similar grading of the degree of metamorphism is present, increasing eastward toward the Sierra Nevada. Dynamothermal metamorphism was strongest along the eastern edge of the "McCowan" schist, where samples exhibit a crenulated structure and a development of false cleavage. Perhaps two periods of metamorphism acted on some of the schists, at Edison. The Sierra Nevada intrusion caused the second or more complete change. Serpentine is associated with several samples along the east edge of the "Dougherty" schist. The origin of the serpentine is not clear; it may have resulted from contact action of this early intrusion, preceding metamorphism.

Outcrop and Well Samples in the Edison Vicinity. Outcrops of schist similar to the "McCowan" were found through T. 29 S., R. 30 E., M. D., in the Cottonwood Creek drainage area. Several thousand feet of these rocks are exposed. They are mostly quartz-graphite-mica schists, some showing a development of slaty cleavage; others contain scattered thin metacrysts of andalusite up to 14 millimeters in length. A fine-grained intrusive 10 feet wide was noted in the schist at this locality.

Northeast and south of Edison, several wells drilled into schist rocks which are probably related to the "McCowan" schist.

The Continental Oil Company "Reay-U. S. L." No. 1 well, in sec. 28, T. 29 S., R. 30 E., M. D., located in front of a schist area in the vicinity of Cottonwood Creek, encountered a muscovite-quartz schist with biotite at a depth of 1093 feet. The rock is very fine-grained; schistose with a slight development of false cleavage. The minerals are mostly quartz and muscovite. Quartz veining is present, and parallels the schistosity. The veins carry scattered crystals of brown biotite and a small amount of andalusite. Some of the andalusite is developed independently.

Near Arvin, the General Petroleum Corporation "Mattson" No. 1 well, in sec. 1, T. 32 S., R. 29 E., M. D., cored a quartz-biotite schist at a depth of 8843 feet. The texture is fine-grained and granulose. The principal mineral is quartz, which has been partially recrystallized. Biotite is prominent, and is oriented parallel to the schistosity. A few muscovite crystals have developed at an angle to the schistosity. A very small amount of graphite is present.

The L. C. Morton "Barlow Farms" No. 1 well, in sec. 25, T. 31 S., R. 29 E., M. D., cored a quartz-chlorite-graphite schist at 5900 feet. Under the microscope, this rock is seen to be fine- to medium-grained, and shows a palimpsest structure. Chlorite and sooty graphite are abundant, and this combination causes the slide to have a dusty, obscure appearance.

The Edward Gieck "Woodworth" No. 1 well, in sec. 30, T. 31 S., R. 30 E., M. D., found quartz-tourmaline-graphite-biotite schist at 5164 feet. Abundant stout tourmaline metacrysts occur with graphite and biotite in a recrystallized quartz field (pl. 16 *B*).

Basement Oil Accumulation in the Edison Oil Field (Discovery June 29, 1945). At the present time, about 1500 acres of schist produce oil in the Edison field. Intervals open to production range from 35 to 1436 feet; the thickness of the zone opened is governed by bottom-water control. Until April 1, 1947, schist production amounted to 5,412,253 barrels

of oil from 112 wells. Gravity ranges from 12 to 30 degrees A. P. I. Initial daily production varies from pumpers of 10 barrels to flowing wells of 2400 barrels.

The source of the oil is the westerly expanding Tertiary sedimentary basin. The oil has migrated up dip and moved into pore and fracture spaces of the structurally higher schist, much as it would into a dolomitic limestone under similar conditions. Suitable faulting, to the north and west of the field, has no doubt aided this migration.

A comparison of the distribution of the schists in the field with the character of the wells and the gravity of the oil indicates that the type of schist has little, if any, control on the accumulation. Later fracturing of the schists has been most intense at the crest of the structure, facilitating the accumulation of oil. A northwest fault system intersects a northeast fault system within the field. Several local segments caused by larger fault intersections, on the valley side, furnish better production.[11]

SUMMARY AND CONCLUSIONS

A review of the thin sections from well samples has shown the basement rocks buried below the Great Valley sediments to be divisible into two main groups: the metamorphic rocks derived from sediments and igneous intrusives, and a younger igneous group (Sierra Nevada), which was the chief cause of metamorphism in the older rocks. The metamorphics are remnants of a roof over the younger granitic intrusion.

The ''McCowan'' schist at Edison and its quartz-mica-graphite schist counterpart in the vicinity of Terra Bella, were derived from carbonaceous clays and very fine silts. They are considered the oldest rocks in the collection. The derivation of the ''Hershey schist'' is not clear. It is assumed to have originated from fine sands, related to the ''McCowan'' sediments. The few scattered quartzites in the Valley may belong to this group.

No fossils have been found in these rocks. An incomplete field comparison of cores with type localities of schists in the Sierra Nevada indicates a lithologic affinity with the Mariposa, rather than the supposedly older Kaweah and Kernville series.

Metamorphism in these rocks grades from very low, in the center of the Valley, to moderate, approaching the Sierra Nevada. This is shown by the increased development of biotite in an easterly direction.

Either during or after deposition, the fine clastics were intruded by fine-grained igneous rocks, in the form of sheets and dikes. These rocks consist of malchite, aplite, and diabase. The eastern portion of the intrusive body forms the ''Dougherty'' schist of Edison, which grades into the hypabyssal intrusives of the Edison-Mountain View area. Other scattered occurrences of this older igneous group are found along the east side of the San Joaquin and Sacramento Valleys.

From Edison west, diorites and occasional quartz diorites have been found in a number of wells. They have a green to gray-green color, caused by alteration and the formation of chlorites and epidotes. Deep central Valley wells, at Rio Bravo and Rosedale, encounter dark, fine-grained, slightly altered gabbros. If these igneous rocks all belong to the same period of intrusion, they could be differentiates of the same magma, with a tendency to become more acidic toward the east. They may have been a

[11] Huey, A. S., and Beach, J. H., oral communication.

portion of a "parent batholith" older than the Sierra Nevada. The age of the "parent batholith" is not known. It may range from Triassic to Jurassic.

This intrusion was followed by a period of intense compression and folding indicated by the attitude of the original bedding. The resultant complex series then underwent a period of granitic invasion (Nevadian). Separate bodies of these intrusives can be recognized in the field by their fresher, coarser-grained aspect. They range from hornblendite to granite, quartz diorite being by far the most common. The younger crystalline rocks are distributed along the east side of the Sacramento and San Joaquin Valleys; in the San Joaquin Valley they form two provinces, one north of Fresno, the other between Delano and Bakersfield ("Kern Arch"). An indication of differentiation is present in these provinces, the rocks becoming more acidic to the east.

The metamorphism of the rocks is regional; their minerals and habit relate them to the epizone. Along the margins of the younger granite, dynamothermal and contact metamorphism are of a low grade. Local serpentinization, probably related to the early intrusion, occurs on the east side of the "Dougherty" schist, at Edison. Serpentine was found in one well drilled in the northernmost part of the Sacramento Valley; serpentine-invaded rock was found in a well near Chico; and in another well northeast of Madera.

Metamorphism has caused various grades of schistosity in the rocks. Recrystallization and schistosity are usually parallel with the bedding of the sediments. The minerals are mostly oriented in the plane of schistosity, although a few anti-stress minerals have developed. The schistosity is never so complete in the igneous rocks that some hint of the original texture does not remain.

Orogenic stresses throughout the Tertiary have caused fracturing and faulting in the basement rocks. This is particularly evident in closely drilled areas such as Edison.

The discovery and development of a substantial amount of oil at Edison demonstrates that the basement complex can be a reservoir for petroleum under favorable geologic and structural conditions.

LIST OF BASEMENT SAMPLES BY GEOGRAPHIC LOCATION

San Joaquin and Sacramento Valleys

Listed by
Section, Township and Range

Sec., T. & R.	Operator and well no. (or locality of outcrop	Depth	Sample no.
N/W MDB&M			
	Butte County		
11–23N/1W	Pacific Western-Getty "Independent Exploration-Cana" #1	6800±	52
	Tehama County		
8–29N/2W	Texas Co. "Jelly Bend" #18-8	7106–7116	181
N/E MDB&M			
	San Joaquin County		
5–1N/8E	Richfield Oil Corp. "Stockton" #1	8539–8544	134
6–1N/9E	Richfield Oil Corp. "East Stockton" #2	6368–6376	133
1–4N/6E	Bankline Oil Co. "Community" #1	5758–5765	61
	Sacramento County		
19–7N/6E	Independent Exploration Co. #1	4801	27
	Placer County		
19–11N/7E	Rocklin Quarry	Outcrop	51
	Sutter County		
12–16N/1E	Shell Oil Co. "Marysville Comm." #C-1	6561–6563	112
35–16N/1E	Buttes Oil Field Co., Ltd. "Sophie-Davis" #2	7011–7014	72
	Butte County		
25–19N/2E	Pacific Western Oil Corp. "Greenlee" #1	3475–3477	184
31–20N/1E	Superior Oil Co. "Dodge Land" #1	7885–7888	53
17–21N/1E	Richfield Oil Corp. "Chico" #1	6997–7005	122
S/E MDB&M			
	Mariposa County		
15–7S/17E	Permanente quarry, Planada	Quarry	145
17–8S/17E	NW/4 NW/4, Mariposa Co., schist outcrop	Quarry	22
	Madera County		
15– 9S/16E	Union Oil Co. "Gamble" #7	3080–85	193 N.R.*
7–10S/14E	Pure Oil Co. "Chowchilla" #1	8373–8378	119
22–10S/17E	Barnhart-Morrow "Arnold" #1	3059–3072	75
28–10S/17E	Thomas Blake "Chuck" #1	3610 (?)	223 N.R.
1–10S/18E	W/4 corner sec., chiastolite schist	Outcrop	21
14–10S/18E	Union Oil Co. "Archibald" #1	700–710	130
27–10S/18E	Union Oil Co. "Moses" #1	1720–1730	131
33–10S/20E	W. Little Table Mt., loc. 1200′ N & 400′ W of S/4 corner of sec.	Outcrop	59
5–11S/18E	Union Oil Co. "Floto" #1	2660–2670	126
35–11S/18E	Union Oil Co. "Pacific Land Co." #1	3660–3670	129
22–11S/19E	Union Oil Co. "Smith" #1	1165–1175	128
	Fresno County		
11–11S/21E	Sample A-2, S/2 of sec. 11	Outcrop	45
	Madera County		
6–12S/20E	Union Oil Co. "Foss" #1	1128–1134	127
16–13S/16E	Texas Co. "Gill" #38-16	9150	6
	Fresno County		
22–15S/24E	Hayden Heights	Outcrop	213 N.R.
29–16S/22E	Superior Oil Co. "White" #1	5466–5468	14
	Tulare County		
34–16S/23E	Transcal "Harris" #1	2603	173
21–16S/24E	Amerada Pet Corp. "Community" #21-1	492	142
28–16S/24E	Amerada Pet. Corp. "Community" #28-1	905	143
	Fresno County		
26–17S/19E	Amerada Pet. Corp. "Lawton" #58-26	11978–11984	65
	Tulare County		
1–17S/24E	Schneider, Winnifred "Pritchett" #1	1144–1147	171
	Kings County		
36–18S/22E	Continental Oil Co. "Drummond" #1	7904–7907	64

* Samples marked "N.R." were not run; these sample numbers are not shown on the accompanying maps.

LIST OF BASEMENT SAMPLES BY GEOGRAPHIC LOCATION—Continued

Sec., T. & R.	Operator and well no. (or locality of outcrop)	Depth	Sample no.
	Tulare County		
15–18S/23E	McDuffie, W. C. "Bennett" #1	5335–5342	180
	Monterey County		
35–19S/7E	C.C.M.O. "Salenco" #1 (Salinas Valley)	2620	194 N.R.
	Tulare County		
33–19S/24E	Richfield Oil Corp. "Tulare Comm." #1	5353–5356	13
35–20S/24E	Richfield Oil Corp. "Churchill" #1	5562–5566	111
29–20S/25E	Brittain Terminal Co. "Gieck-Stephens" #1	4028	100
1–21S/25E	Richfield Oil Corp. "Hewitt" #1	3401	26
27–21S/25E	Trico Oil & Gas Co. "Callison" #1	4606–4631	11
33–21S/25E	Tide Water Assoc. "Hoffman" #24	5063	154
21–21S/26E	Tide Water Assoc. "Core Hole" #76–21	2560	114
34–21S/26E	Tide Water Assoc. "Core Hole" #54-34	2714	69
35–21S/26E	Tide Water Assoc. "Core Hole" #84-35	2228–2233	115
6–22S/26E	Union Oil Co. "Reid" #22-6	3913–3923	198 N.R.
8–22S/26E	Union Oil Co. "Griffen" #45-8	3728	199 N.R.
11–22S/26E	Tide Water Assoc. "Core Hole" #87–11	2724–2734	73
15–22S/26E	Turner "Glaze" #1	3279–3282	77
30–22S/26E	General Pet. Corp. "Moran" #42-30	4501–4514	224
19–22S/27E	Richfield "Terra Bella Comm." #1-1	2343–2353	117
21–22S/27E	Gene Reid "Murray" #1	1430	200 N.R.
27–22S/27E	Hub Oil Co. "Andrews" #1	1485	101
28–22S/27E	Richfield "Terra Bella Hastings" #1	1734–1741	118
29–22S/27E	Richfield "Terra Bella Adams" #1	1912–1917	116
35–22S/27E	Stout, Geo. W. "Stout" #1	1002	28
35–22S/27E	Stout, Geo. W. "Stout" #1	1070	33
	Fresno County		
13–23S/15E	Cretaceous congl. N. of Big Tar Canyon	Outcrop	10
	Tulare County		
9–23S/25E	Continental "Pixley Comm." #1	7891–7900	2
16–23S/26E	Barnsdall Oil Corp. "Lombardi-Security" #1	4174–83	135
16–23S/26E	Barnsdall Oil Corp. " "	4203–23	136
16–23S/26E	Seaboard "Security" #1	4124–4127	3
17–23S/26E	Jergins "Calif. Grape" #18	4620–4634	166
29–23S/26E	Shell Oil Co. "Sunnyvale Comm." #14-1	4822–4825	197
17–23S/27E	Tannehill, L. B. "Hunsaker" #1	2330	149
22–23S/27E	Tannehill, L. B. "Tannehill" #1	1442–1468	132
7–23S/28E	Haggerty and Caine #1	704–740	110
1–24S/26E	Texas Co. "Graham-Loftus" #77-1	3535	30
1–24S/26E	Texas Co. "Graham-Loftus" #77-1	3531–3537	96
1–24S/27E	Ducor Oil Co. "Muller" #1	1320–1344	70
22–24S/27E	Vedder Bros. "Hart" #1	2312	19
23–24S/27E	Amalgamated "Konda" #5	1908	35
34–24S/27E	Lomi Oil Co. "Burnell" #1	2474–2492	125
	Kern County		
20–25S/26E	O'Kane & Braine "Wheeler" #1	6685–6695	182
21–25S/26E	Shell Oil Co. "Bell" #52-12	6330–6336	15
1–25S/27E	Amerada Pet. Corp. "Jasmine" C	1873–1888	79
2–25S/27E	Amerada Pet. Corp. "Jasmine" A	1895–1896	78
3–25S/27E	Dawson, A. E. #1	2650	5
4–25S/27E	Western Gulf Oil Corp. "Richgrove Comm." #1	2643–2653	120
8–25S/27E	Tide Water Assoc. "Quinn" #46	3776–3786	4
8–25S/27E	Western Gulf "Quinn" #A-1	3565	124
15–25S/27E	Barnhart-Morrow "Quinn" #1	2823–2836	76
15–25S/27E	Dilimar "Quinn" #1	2907	44
23–25S/27E	C.C.M.O. Co. "Jasmin" #1	2265	80
31–25S/27E	Cochrane "Bishop" #1	4850	81
35–25S/27E	Bandini Oil Co. "Jasmin" #1	2894–2899	219 N.R.
7–25S/28E	Amerada Pet. Corp. "Jasmine" G	1651–1661	83
17–25S/28E	Hayes-Jenkins Inv. Co. core hole	1170±	37
17–25S/28E	Wilshire Annex "Amalgamated" #1	1306	23
31–25S/28E	C.C.M.O. Co. "Villard" #A-1	2552	94
35–26S/25E	Shell Oil Co. "KCL" #83A	10045	39
15–26S/26E	Tide Water Assoc. "Strine" #32-15	6520–6536	17
11–26S/27E	Superior Oil Co. "Smith" #1	3426–3446	40
11–26S/27E	" " " " "	3446	82
16–26S/27E	Jasper, Fred, "Jasper" #1	4419–4421	68
16–26S/28E	Shell Oil Co. "KCL" #1	1006	12
18–26S/28E	Frame, A. Bruce "Dominion" #1	2476	95
28–26S/28E	Shell Oil Co. "Knapp" #2	2262	84
8–27S/26E	Shell Oil Co. "KCL" #A-58-8	9281	43
12–27S/26E	C.C.M.O. Co. "Famoso" #12-1	6855	7
9–27S/28E	Shell Oil Co. "Vedder" #1	3099–3117	62
13–27S/28E	Superior #1	1810	97
33–28S/25E	Union Oil Co. "Pacific States" #21-33	13361	24
2–28S/27E	Gene Reid "Lorraine" #1	5874–5875	195

LIST OF BASEMENT SAMPLES BY GEOGRAPHIC LOCATION—Continued

Sec., T. & R.	Operator and well no. (or locality of outcrop)	Depth	Sample no.
	Kern County—Continued		
5-28S/27E	Standard Oil Co. #34-5	7185	183
9-28S/27E	Standard Oil Co. #42-9 (2 samples)	6209	1
34-28S/27E	Richfield Oil Corp. "Kramer" #1	7728-7730	16
28-28S/28E	Seaboard Oil Corp. "Fuhrman" #1	5251-5261	18
29-28S/28E	Tide Water Assoc. "M. & S." #113	6147-6152	208 N.R.
30-28S/28E	Tide Water Assoc. "Luck" #154	5994-5998	155
36-28S/28E	Range Oil Co. #1	4693±	67
4-28S/29E	Maurer & Fisher "Core Hole" #1	1015-1019	222 N.R.
16-28S/29E	Pebble Beach "Olcese" #1	1671	85
18-28S/29E	Honolulu Oil Co. #76	3540±	36
18-29S/26E	Standard Oil Co. "KCL" #11-44	13469	147
30-29S/26E	Standard Oil Co. "KCL" #12-6	13661-13664	71
7-29S/27E	Texas Co. "Camp-West-Lowe" #1	10118	32
17-29S/27E	General Petroleum Corp. "Calloway" #66	10052-10055	186
22-29S/27E	Western Gulf Oil Corp. "KCL" #B-45	10589	41
23-29S/27E	Meridian "Fee" #2	8530	42
14-29S/29E	Amerada Pet. Corp. "Waglay" #27-14	4515	172
15-29S/29E	Amerada Pet. Corp. "S.P." #2	4385-4387	121
21-29S/29E	Standard Oil Co. #45-21	5000-5002	161
21-29S/29E	Standard Oil Co. #72-21	4411-4421	157
23-29S/29E	Amerada Pet. Corp. "S.P." #58-23	5328-5349	160
29-29S/29E	Standard Oil Co. #72-29	5522-5525	203 N.R.
28-29S/30E	Continental Oil Co. "Reay-U.S.L." #1	1093-1097	191
29-29S/30E	Midway Northern "Brown" #1	3509	86
31-29S/30E	Richfield Oil Corp. "S.P." #15-1	5260	156
3-30S/29E	British American "Portals" #43-3	5535-5537	175
11-30S/29E	General Petroleum Corp. "Speed" #28-11	2902-2922	165
13-30S/29E	Jergins Oil Co. "McCowan 13A" #1	1768	187
13-30S/29E	Jergins Oil Co. "McCowan 13A" #2	1747	188
13-30S/29E	Jergins Oil Co. "McCowan 13A" #4	1820	189
13-30S/29E	Jergins Oil Co. "McCowan" #B-7	1223	87
13-30S/29E	Jergins Oil Co. "McCowan" #13-1	3739	88
13-30S/29E	Jergins Oil Co. "McCowan" #S-2	1559-1562	214 N.R.
13-30S/29E	Jergins Oil Co. "McCowan" #13B-5	?	215
13-30S/29E	Magee, H. H., "Brockman" #3	2296-2300	159
14-30S/29E	Jergins Oil Co. "Dougherty" #5	2655	123
"	" " "	"	137
14-30S/29E	Jergins Oil Co. "Dougherty" #6	2590-2596	167
14-30S#29E	Jergins Oil Co. "Hershey" #3	2372-2377	169
14-30S/29E	Jergins Oil Co. "Hershey" #9	1676	29
14-30S/29E	Jergins Oil Co. "Hershey" #9A	1834-1839	190
14-30S/29E	Jergins Oil Co. "Hershey" #S-1	2172-2192	168
14-30S/29E	Magee, H. H. "Dougherty" #1	2917±	150
14-30S/29E	Magee, H. H. "Dougherty" #3	2500±	217 N.R.
14-30S/29E	Montery Explor. Co. "Citizens" #2	2776-2782	138
14-30S/29E	Montery Explor. Co. "Citizens" #2	2832-2840	179
14-30S/29E	Monterey Explor. Co. "Citizens" #3	2902-2911	170
15-30S/29E	Monterey Explor. Co. "Duff" #15	3520	25
15-30S/29E	Monterey Explor. Co. "Duff" #9	3619±	139
15-30S/29E	Monterey Explor. Co. "Duff-Shell" #1A	3344-3348	163
15-30S/29E	Monterey Explor. Co. "Duff-Shell" #10	3563	216
15-30S/29E	Monterey Explor. Co. "Duff-Shell" #15 (Duplicated—see #25)	3515-3520	109
15-30S/29E	Monterey Explor. Co. "Duff-Shell" #17	3579-3582	225 N.R.
15-30S/29E	Oceanic Oil Co. "Osborne" #1	3576	211
16-30S/29E	Richfield Oil Corp. "Cauley" #2-1	4795-4804	176
18-30S/29E	Tide Water Assoc. "Alexander" #4	4443	146
21-30S/29E	Federal Oil Co. "Federal-Omaha" #1	5442	152
22-30S/29E	Jergins Oil Co. "Nozu" #1	3124-3136	210 N.R.
23-30S/29E	Jergins Oil Co. "Handel" #1	2750-2760	178a
"	" " "	2623	178b
23-30S/29E	Jergins Oil Co. "Jergins-Texas Fee" #15	1856	74
23-30S/29E	Jergins Oil Co. "Texas Fee" #14	2044-2047	60
23-30S/29E	Jergins Oil Co. "Jergins-Texas Fee-23" #17	1805	177
23-30S/29E	Jergins Oil Co. "Texas Fee" #25	3025-3041	158
23-30S/29E	Jergins Oil Co. "Texas Fee" #11	2576-2597	226 N.R.
23-30S/29E	Texas Co. "Hintz" #1	2015	174
23-30S/29E	Jergins Oil Co. "Jergins-Texas" #19	2127-2130	212 N.R.
24-30S/29E	Jergins Oil Co. "Ross" #2	1219	99
25-30S/29E	Mettler & Sons "Mettler" #1	1740-1755	66
25-30S/29E	Berry "Edison-Duff" #1	1335	98
26-30S/29E	Barnsdall Oil Corp. "Slininger" #1	2375-2377	55
26-30S/29E	Mohawk "Weicheldt" #1	2370	103
26-30S/29E	Richfield Oil Corp. "Lawson-Bennett" #1	3487-3492	164
28-30S/29E	Continental Oil Corp. "Porter" #1	4994-4999	218
29-30S/29E	Shell Oil Co. "Porter Day" #1	8386	89
33-30S/29E	Ohio Oil Co. "Derby" B-1	5867	91
34-30S/29E	Texas Co. "Bastian" #1	4608	31
35-30S/29E	Petroleum Production Co. "Welsh" #1	2679	104
36-30S/29E	Ohio Oil Co. "Cauley" #2	1247	107
36-30S/29E	Richfield Oil Corp. "Cauley" #1	1302-1304	151

LIST OF BASEMENT SAMPLES BY GEOGRAPHIC LOCATION—Continued

Sec., T. & R.	Operator and well no. (or locality of outcrop)	Depth	Sample no.
	Kern County—Continued		
19–30S/30E	Independent Exploration Co. "Mettler" #1	1399	153
29–30S/30E	R & R Development Co. #1	1104	102
32–30S/30E	R & R Development Co. #3	862	90
2–30S/33E	Sample B (dike)	Outcrop	221 N.R.
3–31S/29E	Union Oil Co. "DiGiorgio" #71-3	4540–4544	201
3–31S/29E	Union Oil Co. "DiGiorgio" #62-3	4682	204
3–31S/29E	Richfield Oil Corp. "DiGiorgio" #1-3	5303–5340	162
3–31S/29E	Tide Water Assoc. "DiGiorgio" #1	5486	50
10–31S/29E	DiGiorgio Fruit Co. #4	5843	63
10–31S/29E	DiGiorgio Fruit Co. "DiGiorgio" #35-10	6185	140
10–31S/29E	DiGiorgio Fruit Co. "DiGiorgio" #48-10	6410–6416	113
10–31S/29E	Western Gulf Oil Corp. "DiGiorgio" #1	5878	205 N.R.
10–31S/29E	Western Gulf Oil Corp. "DiGiorgio" #1	5951–5956	206
10–31S/29E	Western Gulf Oil Corp. "DiGiorgio" #1	6153–6156	207 N.R.
12–31S/29E	DiGiorgio Fruit Co. #1	2253–2258	8
12–31S/29E	DiGiorgio Fruit Co. #2	3125	9
15–31S/29E	Shell Oil Co. "Greer" #1	6171	92
16–31S/29E	Texas Co. "Jewett" #2	7712–7717	106
23–31S/29E	Morton, L. C. "Jewett" #1	6697–6699	34
25–31S/29E	Morton, L. C. "Barlow Farms" #1	5900	38
26–31S/29E	General Petroleum Corp. "Arvin" #1	7452	93
35–31S/29E	Continental Oil Co. "Derby" #1	8889–8899	148
4–31S/30E	Rock Pile, loc. 300′ N & 1000′ W of SE cor. of sec. 4	Outcrop	47
7–31S/30E	DiGiorgio Fruit Co. "DiGiorgio" #3	1635	58
13–31S/30E	Basement sample proj. sec. 13, 3800′ N & 600′ W of SE corner	Outcrop	56
19–31S/30E	Gene Reid "Angus" #1	4595–4605	202 N.R.
20–31S/30E	Hall-Baker "McCowan" #1	1883	105
24–31S/30E	Basement sample proj. sec. 24, 400′ S & 2200′ N of northeast corner	Outcrop	57
30–31S/30E	Edward Gieck "Woodworth" #1	5164–5170	185
1–32S/29E	General Petroleum Corp. "Mattson" #1	8843	108
25–32S/29E	L. S. Gilmour "Tejon" #2	1265–73	192 N.R.
36–32S/29E	L. S. Gilmour "Indexco-Tejon" #1	2445	209 N.R.
16–32S/30E	Schist sample loc. 2200′ S & 1000′ E of NW cor. sec. 16 (in sec. 17)	Outcrop	49
S.B.B. & M.			
12–10N/19W	Reserve Oil & Gas "Tejon" #3	1821–1844	54
19–11N/18W	Richfield Oil Corp. "Tejon" #2	4956–4959	20
34–12N/18W	Burnam, T. W. "Chiquita" #2	1675±	48
29–12N/19W	G. B. Finch & Assoc. "Tejon" #6	1915–1918	196 N.R.
	Outside Valley Samples		
	Los Angeles County		
9–1S/13W	Seaboard Oil Corp. "Park" #1	1800	141
12–3S/15W	Larco Oil Co. "Van" #1	7590	46
	Imperial County		
26–10S/9E	Pure Oil Co. "Truckhaven Unit" #1	6047–6053	144
	Wyoming		
50N/83W	6 P.M. Sample A (along Highway #16, between Buffalo & Tensleep, Johnson County, Wyoming)	Outcrop	221 N.R.

MINES AND MINERAL RESOURCES OF NAPA COUNTY, CALIFORNIA

By Fenelon F. Davis *

OUTLINE OF REPORT

ILLUSTRATIONS

ABSTRACT

Napa County, bordering San Pablo Bay, is one of the original 27 counties formed in 1850. The county seat, Napa (city), is about 45 miles north of San Francisco on Highway 29. The county is characterized by mountain ranges and intermontane valleys which trend northwestward, and lie in the southern part of the northern Coast Ranges of California. The surface rocks exposed here include a northern area of Jurassic Franciscan sediments and associated basic intrusives, strips of Shasta (Cretaceous) sediments along the eastern and western borders, patches of Eocene and Miocene sediments in the south, and extensive Pliocene volcanics east of Napa Valley.

Napa County ranked thirtieth among the 58 counties of the state in value of mineral production in 1945. The value of mineral production in 1946 was $1,019,786 and was derived from mineral water, pumice, quicksilver, sandstone, and miscellaneous stone. The recorded value of mineral production from 1862 to 1947 was $45,134,431.

Chrysotile asbestos occurring in a serpentine area 18 miles northeast of Napa was mined from 1941 to 1945. It was milled in a modern electrically operated plant at the mine and the finished product was used as insulating materials, plaster, and stucco, for war housing and war-plant buildings.

Chromite is found in northeastern Napa County associated with serpentine masses. A total of 2132 tons of chromite was shipped between 1916 and 1941. Shipments during the war years 1941-45, when high prices for chrome ore prevailed, constituted only 19 percent of all the chromite reaching the market from Napa County.

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Clays from Napa Valley have been used in brick and cement.

Magnesite was produced from 1916 to 1924. Sea water magnesia has largely replaced the product of the magnesite mines except in the case of extremely large high-grade deposits.

Manganese deposits are numerous in northern Napa County interbedded with sediments of the Franciscan formation. About 300 tons of oxide ore was produced in 1918.

Mineral water has made important contributions to the annual value of mineral production. Although the present rate of production is comparatively low it is capable of expansion in the near future. The numerous mineral springs have made Napa County famous as a center of rest and recreation resorts.

Obsidian is potentially valuable as a source of synthetic pumice for use in light-weight building materials. It occurs as a phase of the Pliocene volcanics in the vicinity of Glass Mountain, from which locality it has been traced about 2 miles to the north as a flow.

Petroleum has been produced from the Jurassic sediments of the Knoxville formation in Berryessa Valley at the rate of half a barrel per day.

Pumice occurs on the east side of the Napa Valley as pumiceous tuff and breccia in the thick group of Pliocene volcanics. It was capped by a trachyte flow, part of which has been removed by subsequent uplift and erosion. Present mining operations are 3 to 7 miles east of Napa along Highway 37 in areas where there is no overburden. The pumiceous tuff is removed by scrapers, crushed, washed, dried, and used as an aggregate in building bricks and blocks.

Quicksilver has contributed more to the value of Napa County production than any other mineral. Production figures are recorded for every year since 1862. The first boom period occurred from 1874 to 1878 and another occurred from 1893 to 1899. Since the latter period, production has dropped to a comparatively small figure which has been influenced greatly by fluctuations in price. Mining operations have been chiefly underground although the only present active mine (1947) is an open-pit operation. Some creek gravels have been worked on a small scale. The unstable price structure has discouraged the development of reserves in advance of ore extraction.

Silver sulphides associated with gold in quartz veins were discovered on the slopes of Mount Saint Helena about 1870. Two productive mines were developed, which operated intermittently. More than $1,370,216 in combined silver and gold production between 1874 and 1940 has been reported from Napa County. No production has been reported since 1940.

Building stone, chiefly sandstone and tuff, has appeared in the production figures from Napa County since 1913. Much of the tuff was used in local construction within the county. Production of miscellaneous stone, which includes crushed rock and sand and gravel, was first reported in 1902. This mineral product reached a substantial figure by 1908 and has been a consistent contributor to the value of mineral production since that date. One of the largest rock plants of the San Francisco Bay area is located at Napa. There are also consistent smaller producers.

INTRODUCTION[1]

The American settlers in Napa County were preceded by the Indians and the Spanish explorers. The Pomo Indians established a fishing village or 'nappo' on the shore of the bay, and to this word the name 'Napa' traces its origin. The first white settler, George C. Yount, received a land grant (Rancho Caymus) in 1835, which was followed by additional grants to other settlers during the forties. Napa was one of the original 27 counties formed in February 1850.

GEOGRAPHY[2]

Napa is one of the counties bordering San Pablo Bay. The county seat, Napa (city), is about 45 miles north of San Francisco on State Highway 29. The county is approximately 20 miles wide, 40 miles long, and includes an area of 790 square miles. It is bounded on the west by Sonoma County, on the north by Lake County, on the east by Yolo and Solano Counties, and on the south by San Pablo Bay.

[1] Hoover, M. B., Historic spots in California, counties of the Coast Range, pp. 279-299, 1937.
Gunn, H. L., and Hunt, Marguerite, History of Solano and Napa Counties, vol. 1, pp. 270-271, 1926.

[2] California Blue Book, p. 601, 1946.

The population (28,503) in 1940 was classed at 25 percent urban and 75 percent rural. These percentages shifted in favor of the urban centers during the war years with the influx of workers to the West Coast industries. The estimated county population in 1946 was 42,700. The urban population figures in 1946 were as follows: Napa 13,500, Saint Helena 2100, and Calistoga 1250, representing about 40 percent of the total.

The climate at Napa (city) is typical of a large part of the county. Here the mean temperature ranges from 47° Fahrenheit in January to 67° Fahrenheit in July. The average annual rainfall of 22.7 inches at Napa is exceeded both on the mountain slopes and at the head of the Napa Valley. It has reached a maximum of 60 inches on Mount Saint Helena. These favorable temperatures, coupled with the presence of numerous hot springs, have made Napa County a California vacation land for decades.

The Southern Pacific railroad serves the Napa Valley towns as far north as Calistoga and a number of bus lines connect with the smaller communities. There are 114 miles of paved state highways including Highway 29 running north from Oakland on the eastern shore of San Francisco Bay. State Highway 37 leads from Napa to the quicksilver district at the north end of the county and Highway 28 is a connecting link with the Sacramento Valley to the east. An additional 450 miles of county roads make all points in the county accessible by automobile. The Napa River is navigable for vessels of 12½-foot draft. A 622-acre airport at Napa, a class 4 port, has two 5,000-foot runways and can handle the largest commercial planes now operating.

TOPOGRAPHY

The area covered by Napa County is in the southern part of the northern Coast Ranges of California. It is characterized by mountain ranges and intermontane valleys which trend northwestward and slope southeastward. Tributary canyons are normal to the main trend. In the southwestern half of the county is Napa Valley, about 3 miles wide and 40 miles long, through which the Napa River flows to the sloughs of San Pablo Bay at the southern boundary of the county. Elevations here range from sea level at the valley mouth to 600 feet at the valley head, and then rise rapidly in the next 3½ miles to 4200 feet in the Mayacmas Mountains at the northwest corner of the county.

The northeastern half of the county is separated from Napa Valley by the Howell Range, a southeastern extension of the Mayacmas Mountains of Lake and Sonoma Counties. The area beyond the Howell Range is the locus of a number of smaller valleys, the most important of which are Chiles, Pope, and Berryessa. Of these, Berryessa Valley, 4 miles west of the county's east boundary, is the largest, averaging over 2 miles in width and 10 miles in length. The area is drained chiefly by Pope, Putah, and Eticurra Creeks, which enter Berryessa Valley from the west, northwest, and north, respectively, and merge into Putah Creek on the west side of the valley. From this point Putah Creek flows southeastward through Berryessa Valley for 7 miles, then winds through the mountains an additional 7 miles to the county line, and continues eastward, emptying into the Sacramento River sloughs in Yolo County.

Topographic maps on a scale of 1 to 62,500 or about 1 inch to 1 mile are available for the entire county. The following quadrangles of the United States Geological Survey cover parts of the county: Calistoga,

Capay, Carquinez, Mare Island, Morgan Valley, Saint Helena, and Santa Rosa. The remainder of the county is covered by quadrangles of the Corps of Engineers, United States Army, namely: Mount Vaca, and Sonoma. In addition, the United States Geological Survey has published the Napa quadrangle on the scale 1 to 125,000, or about half an inch to the mile. This Napa quadrangle includes the area covered by the Carquinez, Mare Island, Mount Vaca, and Sonoma quadrangles, the city of Napa being in the center of the map.

GEOLOGY

The general surface geology of Napa County is shown on the *Geologic Map of California*,[3] scale 1 to 500,000, or approximately 1 inch to 8 miles. The map shows a belt of Cretaceous sediments of the Shasta group outcropping along the entire eastern border of the county and extending westward to an average width of about 4 miles. This belt is flanked on the west by a parallel strip of Knoxville sediments about 1½ miles in width extending from the north boundary to the south end of Berryessa Valley. The remainder of the county north of T. 7 N. is covered by Franciscan sediments and their associated basic intrusives. The east flank of Napa Valley is composed of a thick group of Pliocene volcanics. On the west flank of the valley the Shasta is again exposed and is partly overlain by the Pliocene volcanics which extend westward under the valley alluvium.

Two geological cross sections running northeastward through Napa County were made by Osmont.[4] The first section passes through Mount Saint Helena, Oat Hill, and Knoxville. The second section passes through the city of Napa. These sections are accompanied by a detailed discussion of the geological formations encountered en route.

References to additional reports on Napa County chromite, clay, magnesite, manganese, petroleum, and quicksilver will be found in the sections devoted to individual minerals.

INDUSTRIES

Farming is the chief industry of Napa County. The value of agricultural crops produced in 1945 was $12,938,750, being derived from prunes, grapes, poultry, miscellaneous orchard and field crops, dairy products, and animal production. Industrial Napa lies almost at the exact center of Pacific Coast population. Excellent transportation, ample gas and electric facilities, a good municipal water supply, and abundant petroleum products from nearby refineries, have helped factories locate here. The present industrial output includes wearing apparel, gloves, paper, leather, wine, and steel products.

MINERAL RESOURCES

Napa County ranked thirtieth among the counties of the state in value of mineral production in 1945. The minerals produced in 1946 were mineral water, pumice, quicksilver, sandstone, and miscellaneous stone, having a total value of $1,019,786. Other mineral products have been asbestos, building stone, cement, chromite, clay, copper, gold, lead, limestone, magnesite, manganese, onyx, paving blocks, petroleum, sandstone, and silver. The important mineral products are described in alphabetical

[3] Jenkins, Olaf P., Geologic map of California, scale 1:500,000, California Div. Mines, 1938.

[4] Osmont, Vance C., Geological section of the Coast Ranges north of the bay of San Francisco: Univ. California Dept. Geol. Sci. Bull., vol. 4, pp. 39-87, 1904.

order below. Figures showing annual production and value are presented in table 1.

Asbestos

Asbestos is the name used to designate a group of fibrous minerals which can be classed under two heads, amphibole and serpentine. Serpentine is a secondary hydrous magnesium silicate which may be subdivided into the following varieties: common serpentine, dense and massive; picrolite, bladed or coarsely fibrous; and chrysotile, silky with extremely fine, strong fibres. The chrysotile variety of the serpentine class is economically the most important. Its fibres vary from one-eighth of an inch to three inches in length, but are usually less than one inch. The value of the fibre is determined by its length, the long-fibre material being in greater demand. In California asbestos occurs as short cross-fibre veins of chrysotile in massive serpentine derived from peridotite and associated with rocks of Franciscan age. The serpentine rocks of the northern Coast Ranges, some of which occur in Napa County, are therefore logical areas for asbestos prospecting. A sizable local market could be developed for suitable chrysotile fibre, but so far the California output has been insufficient to meet the demand.

Kohler and Chase Asbestos Quarry[5]

Location: SE¼ sec. 4, and part of SW¼ sec. 3, T. 7 N., R. 3 W., M. D., comprising about 285 acres, 18 miles northeast of Napa on Highway 37, and 8½ miles south of Monticello.

Owner: Kohler and Chase, 26 O'Farrell Street, San Francisco; George Q. Chase, president.

The Kohler and Chase asbestos deposit consists of short, silky, cross-fibre veinlets of chrysotile asbestos disseminated in all directions through a body of serpentine. The veinlets range in width from one sixty-fourth of an inch to a maximum of three-quarters of an inch, the average width being about an eighth of an inch. The serpentine is thoroughly sheared, fractured, and "slick." The asbestos fibres are suitable for use in plasters and stucco. They were used in war housing and war-plant buildings from 1941-45, as insulating material.

The property was acquired by the present owners about 1939. Mining operations began in 1941. Ores were removed through two adits driven from the east side of the northwestward-trending hill. The lower adit, about 200 feet below the summit, was 60 feet long but is not open. The upper adit is about 30 feet long and is connected with surface by a 30-foot raise. The surface opening of the latter is about 2 feet in diameter. On the east side of the hill, open-cut operations were carried on. When operations were begun in 1941 the crude ore was transported to San Francisco and run through a pilot mill. A flow sheet was developed, and a 40-ton mill designed and installed at the mine by mid-year, 1942.

Crude ore was trucked around the hill about three-quarters of a mile to an electrically operated mill. The ore was dumped on a grizzly of steel rails spaced with 3-inch openings, and passed down a 45° chute to a bin over a Fort Wayne jaw crusher for coarse crushing. The minus 1 inch product from the crusher was discharged to an automatic feeder feeding an inclined 5- by 20-foot countercurrent dryer fired by a Ray oil burner.

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[5] Averill, C. V., Mineral resources of Napa County: California Div. Mines Rept. 25, p. 216, 1929.
Boalich, E. S., Mineral resources of Napa County: California Min. Bur. Rept. 18, p. 419, 1922.

Table 1. Mineral production of

Year	Quicksilver		Mineral water	
	Flasks	Value	Gallons	Value
Manhattan mine output, 1863-76	3,594	$235,876	[2]	----
1862	444	16,139	----	----
1863	852	35,852	----	----
1864	2,714	124,573	----	----
1865	3,545	162,716	----	----
1866	2,254	119,755	----	----
1867	7,862	360,866	----	----
1868	9,808	450,187	----	----
1869	6,598	302,848	----	----
1870	5,766	330,853	----	----
1871	4,098	258,584	----	----
1872	4,876	321,475	----	----
1873	5,266	423,018	----	----
1874	11,705	1,231,132	----	----
1875	9,453	795,470	----	----
1876	11,303	497,332	----	----
1877	13,127	489,637	----	----
1878	10,810	355,649	----	----
1879	9,446	281,961	----	----
1880	6,830	211,730	----	----
1881	7,746	231,063	----	----
1882	9,013	254,467	----	----
1883	7,784	223,790	----	----
1884	5,188	158,234	----	----
1885	3,891	119,648	----	----
1886	5,656	200,788	----	----
1887	6,247	264,717	----	----
1888	5,150	218,875	----	----
1889	5,402	243,090	----	----
1890	3,934	206,535	----	----
1891	4,896	221,544	----	----
1892	8,612	350,595	----	----
1893	11,505	422,809	----	----
1894	9,705	298,016	97,275	$41,231
1895	9,318	372,500	199,397	99,700
1896	11,411	403,031	218,680	81,335
1897	12,281	459,753	159,896	81,948
1898	12,368	472,972	169,261	63,919
1899	11,696	598,322	171,567	85,964
1900	8,724	403,500	171,000	72,200
1901	7,798	388,176	158,830	109,900
1902	7,142	304,474	236,229	97,048
1903	7,859	333,006	244,400	124,000
1904	[3]5,328	199,586	386,000	104,750
1905	4,853	171,910	279,400	89,500
1906	2,380	86,870	84,000	90,500
1907	2,500	95,400	240,000	103,600
1908	2,340	98,912	145,500	101,090
1909	1,625	80,535	123,072	96,279
1910	646	29,231	152,772	92,960
1911	140	6,441	141,540	86,530
1912	287	12,065	136,750	81,997
1913	287	11,546	151,520	75,548
1914	240	11,772	142,940	73,280
1915	507	45,224	133,387	73,535
1916	1,150	107,525	152,764	93,370
1917	834	78,320	126,124	70,058
1918	1,297	143,850	92,512	59,620
1919	644	58,140	76,860	60,395
1920	266	18,588	80,341	38,621
1921	35	1,659	72,364	55,760
1922	189	5,143	80,481	54,341
1923	157	9,759	69,639	55,757
1924	----	[4]	73,608	53,391
1925	----	----	63,836	44,251
1926	----	[4]	80,376	49,468
1927	776	88,425	81,864	50,116

Napa County, 1862-1946.

Magnesite		Miscellaneous stone,[1] value	Miscellaneous and unapportioned		
Tons	Value		Amount	Value	Substance
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	$93,000	Gold and silver
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	------------	
------------	------------	------------	------------	5,000	Gold and silver.
------------	------------	------------	------------	16,000	Gold and silver.
------------	------------	------------	------------	22,500	Gold and silver.
------------	------------	------------	------------	50,000	Gold and silver.
------------	------------	------------	------------	95,000	Gold and silver.
------------	------------	------------	------------	57,046	Gold and silver.
1,500	$6,000	------------	------------	30,517	Gold and silver.
------------	------------	------------	------------	23,689	Gold and silver.
------------	------------	------------	------------	------------	
1,440	10,240	------------	51 tons	2,040	Infusorial earth.
2,200	17,000	------------	------------	------------	
1,500	11,000	------------	------------	------------	
1,143	13,671	------------	------------	------------	
1,263	19,075	------------	------------	------------	
1,180	17,130	------------	------------	------------	
1,983	17,400	------------	------------	------------	
700	11,622	------------	8,919 tons	6,690	Limestone.
150	450	$500	7,086 tons	8,496	Limestone.
61	915	3,375	290,368 bbls.	434,552	Cement.
12	78	4,019	------------	------------	
------------	------------	500	------------	------------	
------------	------------	2,777	------------	------------	
------------	------------	3,000	------------	------------	
------------	------------	78,728	------------	------------	
------------	------------	138,636	------------	3,151,182	Unapportioned, 1900 to 1909.
------------	------------	122,219	------------	2,893,786	Unapportioned, 1910 to 1913.
------------	------------	127,428	------------	------------	
55	550	172,646	------------	------------	
------------	------------	243,759	------------	8,000	Sandstone.
------------	------------	130,316	------------	756,380	Other minerals.
1,050	9,450	108,387	------------	647,625	Cement, sandstone.
13,960	108,556	88,441	715 tons	11,559	Chromite.
			119,500 cu. ft.	5,500	Building stone (tuff).
			------------	663,586	Other minerals.
40,329	387,930	110,039	844 tons	22,020	Chromite.
			------------	752,706	Cement, clay, copper.
29,163	263,367	82,944	667 tons	38,432	Chromite.
			------------	1,088,154	Cement, gold, silver.
10,112	86,752	70,016	------------	------------	
[4]	------------	74,550	------------	98,382	Magnesite, volcanic ash.
------------	------------	111,100	------------	26,720	Other minerals.
[4]	------------	200,151	------------	52,635	Building stone (red tuff), magnesite.
------------	------------	215,356	------------	70,720	Other minerals.
[4]	------------	261,523	------------	44,351	Magnesite, quicksilver.
------------	------------	177,186	------------	195	Gold.
			------------	1,420	Silver.
			------------	6,120	Other minerals.
------------	------------	207,882	------------	7,817	Gold.
			------------	50,616	Silver.
			------------	25,788	Other minerals.
------------	------------	209,996	------------	7,235	Gold.
			------------	56,435	Silver.
			------------	5,022	Copper, sandstone.

Table 1. Mineral production of

Year	Quicksilver		Mineral water	
	Flasks	Value	Gallons	Value
1928	781	$85,477	70,291	$32,707
1929	2,081	246,747	86,141	90,703
1930	2,000	213,840	43,902	13,837
1931	1,937	168,710	106,062	49,665
1932	647	34,634	33,011	12,293
1933	842	47,059	15,237	9,940
1934	1,706	120,372	47,900	13,900
1935	1,109	60,649	38,000	3,650
1936	737	55,556	55,590	7,245
1937	329	26,051	77,531	15,683
1938	694	46,403	53,152	9,658
1939	691	71,823	94,750	12,650
1940	1,479	245,757	127,681	16,250
1941	1,999	337,726	69,026	19,519
1942	1,905	356,532	41,312	4,890
1943	2,023	363,017	33,506	3,569
1944	1,176	128,570	---	[4]
1945	---	[4]	---	[4]
1946	---	[4]	---	[4]
Totals	362,294	$18,125,382	5,987,277	$2,928,621

Grand total value, $45,134,431.

[1] Includes crushed rock, macadam, rubble, paving blocks, sand, gravel.
[2] Napa Soda Springs have been bottling water for sale since 1860; but no segregated figures available for Napa County previous to 1894.
[3] Flasks of 76½ pounds to June, 1904; of 75 pounds thence, through 1927; of 76 pounds since January, 1928.
[4] See under 'Unapportioned.'

Napa County, 1862-1946 (cont.)

Magnesite		Miscellaneous stone,[1] value	Miscellaneous and unapportioned		
Tons	Value		Amount	Value	Substance
------------	------------	$179,078	------------	$9,000	Other minerals.
			4,356 lbs.	767	Copper.
------------	------------	216,420	------------	17,781	Gold.
			144,180 fine oz.	76,848	Silver.
				556	Other minerals.
			9,275 lbs.	1,203	Copper.
			------------	36,532	Gold.
------------	------------	[4]	464 lbs.	23	Lead.
			266,386 fine oz.	102,559	Silver.
			------------	164,989	Miscellaneous stone and sandstone.
			1,945 lbs.	177	Copper.
------------	------------	145,920	------------	14,766	Gold.
			60,009 fine oz.	17,403	Silver.
			------------	200	Other minerals.
------------	------------	115,982	------------	6,724	Asbestos, pumice, sandstone.
------------	------------	142,143	------------	10,400	Pumice and sandstone.
------------	------------	256,982	------------	6,960	Asbestos, pumice, paving blocks, sandstone.
			------------	3,894	Gold.
------------	------------	[4]	------------	8,470	Silver.
			------------	121,403	Chromite, copper, pumice, miscellaneous stone.
------------	------------	[4]	------------	504,352	Chromite, copper, lead, gold, pumice, sandstone, silver, miscellaneous stone.
			1,156 lbs.	140	Copper.
------------	------------	246,665	------------	12,355	Gold.
			------------	51,641	Silver.
			------------	3,611	Other minerals.
			4,450 lbs.	436	Copper.
------------	------------	[4]	------------	64,260	Gold.
			------------	95,895	Silver.
			------------	421,311	Pumice, sandstone, miscellaneous stone.
			9,667 lbs.	1,005	Copper.
			------------	115,710	Gold.
------------	------------	[4]	------------	197,696	Silver.
			------------	316,011	Onyx, pumice, sandstone, miscellaneous stone.
------------	------------	[4]	------------	567,582	Onyx, copper, gold, silver, pumice, sandstone, miscellaneous stone.
			2,406 lbs.	284	Copper.
			------------	12,250	Gold.
------------	------------	[4]	------------	25,686	Silver.
			------------	623,719	Asbestos, chromite, pumice, sandstone, miscellaneous stone.
------------	------------	[4]	------------	1,086,216	Asbestos, pumice, sandstone, miscellaneous stone.
------------	------------	[4]	------------	581,971	Asbestos, pumice, miscellaneous stone.
------------	------------	[4]	------------	581,116	Asbestos, chromite, mineral water, pumice, miscellaneous stone.
------------	------------	[4]	------------	628,974	Asbestos, mineral water, quicksilver, pumice sandstone, miscellaneous stone.
------------	------------	[4]	------------	1,019,786	Mineral water, pumice, quicksilver, sandstone, miscellaneous stone.
107,801	[4]$981,186	[4]$4,248,664	------------	$18,850,578	

A cyclone air separator removed the fibres which were screened and graded on 4- by 8-foot, eccentric, head mounted, shaking screens. A D-18 disintegrator and a D-12 disintegrator made additional fibre separations. The disintegrators were also connected with cyclone air separators and shaking screens. The end products were passed to a bagging machine where the pulverized asbestos was put up in 100-pound paper bags. This product was marketed under the trade name "Plastene" and used in plaster and stucco for fireproof construction. Operations ceased in 1945 and the mill machinery is now partly disconnected.

Chromite

Chromite is found in the northeastern part of Napa County associated with serpentine masses. The distribution of these deposits has been shown by Jenkins [6] and the geology has been reported by Dow and Thayer.[7] Their report contains descriptions of individual mines and prospects gathered during the war years. It also includes production tables covering the period from 1915-44 for all the northern Coast Range counties of California. Seventy-two percent of the ore shipped from Napa County reached the market during the years 1916-18, but the ore shipped from 1941-44 constituted only 19 percent of the total. In view of these facts and the high prices paid for chromite ore during the latter period, the future of chromite in Napa County does not appear important.

Clay

Local Napa Valley clays have been used in the past for manufacturing brick and cement.[8] An interesting deposit of high-grade residual kaolin near Calistoga has been described by Dietrich,[9] whose report is accompanied by a sketch map of the property.

Magnesite

Large quantities of magnesite were produced in Napa County from 1916-20 during the first world war, but no production has been made since 1924. Many plants which had been experimenting with the production of magnesia from sea water got into commercial operation about 1938. Four such plants are now operating in California, using either sea water or salt-plant bitterns. Thus sea water magnesia has largely replaced the product of the magnesite mines so that only the large high-grade bodies of magnesite can now be worked profitably. The magnesite deposits of Napa County have been discussed in a special bulletin by Bradley.[10]

Manganese

A number of manganese deposits occur in the northern part of Napa County interbedded with sediments of the Franciscan formation. The geology of these deposits has been reported by Jenkins [11] and contributing authors, and the report contains a map [12] showing their distribution. A small shipment of oxide ore from Napa County was made in 1918.

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[6] Jenkins, Olaf P., Economic mineral map of California no. 3, chromite, scale 1:1,000,000, California Div. Mines, 1942.

[7] Dow, D. H., and Thayer, T. P., Chromite deposits of the northern Coast Ranges of California: California Div. Mines Bull. 134, pt. 2, chapt. 1, pp. 20-25, 34, 1946.

[8] Bradley, W. W., Mineral resources Napa County: California Div. Mines Rept. 14, pp. 262-268, 1914.

[9] Dietrich, W. F., The clay resources and the ceramic industry of California: California Div. Mines Bull. 99, pp. 132-135, 1928.

[10] Bradley, W. W., Magnesite in California: California Div. Mines Bull. 79, pp. 53-58, 1925.

[11] Jenkins, Olaf P. and others, Manganese in California: California Div. Mines Bull. 125, pp. 81, 145-146, 1943.

[12] Jenkins, Olaf P., Economic mineral map of California, no. 5, manganese, scale 1:1,000,000, California Div. Mines, 1943.

Mineral Water

Mineral water was formerly an important contributor to the annual value of mineral production in Napa County. The year 1930 introduced a prolonged period during which people were both unwilling and unable to frequent the health and pleasure resorts centered around the mineral springs. They further curtailed their drinking habits by declining to purchase delivered bottled water, with the result that production fell off proportionately. In addition, with the passing of some of the pioneers part of the business passed into less aggressive hands. Finally, in 1944 a disastrous fire at Napa Soda Springs eliminated one of the leading producers who had supplied mineral water continuously for 75 years, and county production figures reached an all-time low. With the installation of a temporary bottling plant at Napa Soda Springs production has shown a substantial increase, and plans for expansion as equipment becomes available augurs well for the future. The presence of a definite market for mineral water is indicated by the California production for 1946, which reached a near all-time high of 33,397,902 gallons. Napa County, with its numerous mineral springs and proximity to a large center of population, should be able to share in this market. Most of the springs are described in a report by Averill,[13] in which he presents analyses of the water contained therein.

Grigsby Soda Springs (Samuels Soda Springs)[14]

Location: sec. 28, T. 9 N., R. 4 W., M. D., about 10 miles northwest of Monticello.

Owner: T. B. Grigsby, Monticello, who purchased the Samuels Soda Springs in 1946 and changed the name to Grigsby Soda Springs.

The water of Grigsby Soda Springs is consumed chiefly by guests, although a small amount is sold locally to purchasers who furnish their own containers.

Napa Soda Springs[15]

Location: secs. 2 and 3, T. 6 N., R. 4 W., M. D., about 7 miles north of Napa.

Owner: Napa Soda Incorporated, 25 Taylor Street, San Francisco; Al Nasser, president.

The present owners purchased the Napa Soda Springs in March 1944. A disastrous fire had previously destroyed the restaurant, bottling works, rotunda, and one hotel building. One building was reroofed and equipped with a bottling machine capable of turning out 650 dozen half-pint bottles of soda water per month, which is marketed in the Bay area. Except for a short time after the fire, 1942-44, Napa soda water has been on the market since 1856.

Obsidian

Obsidian is a natural glass resulting from the rapid cooling of acid magma. When such magmas reach the surface, flow out as lava, and cool quickly without relief of pressure, obsidian is formed. Consequently streaks or zones of obsidian can occur in any group of volcanic rocks such as the Pliocene volcanics of Napa County. Chemically, obsidian is a

[13] Averill, Charles V., op. cit. pp. 220-225, 1929.
[14] Averill, C. V., op. cit., p. 224, 1929.
Bradley, W. W., op. cit., p. 281, 1914.
Waring, Gerald A., Springs of California: U. S. Geol. Survey Water-Supply Paper 338, p. 155, 1915.
[15] Averill, C. V., op. cit., p. 222, 1929.
Bradley, W. W., Mines and mineral resources of Napa County: California Div. Mines Rept. 14, p. 279, 1914.
Waring, Gerald A., op. cit., p. 155, 1915.

sodium-potassium-aluminum silicate, containing minor amounts of iron, calcium, and magnesium, and about one percent combined water.

The Indians used obsidian to make cutting implements and weapons because its remarkable conchoidal fracture permitted working it into the desired forms. Later it became useful as an ornamental stone and in the gem industry. Recent research has indicated that, owing to its contained water, obsidian may be expanded at high temperatures to many times its original volume with a loss in weight. These expanded glasses are actually synthetic pumice and are in demand under the commercial name "perlite", wherever light-weight building materials are important.

Glass Mountain Deposit[16]

Location: Southern half of Rancho Carne Humana or NE¼ sec. 23, T. 8 N., R. 6 W., M. D. (projected). This deposit is about 2½ miles northeast of Saint Helena and half a mile east of the Southern Pacific railroad on the Silverado Trail.

Owner: Over 20 acres, formerly part of the John C. Weinberger property, are now owned by the Basalt Rock Company, Incorporated, Napa.

The Glass Mountain obsidian is exposed in a roadcut two-tenths of a mile north of Lodi Avenue on the Silverado Trail, where it dips 70° SW. It is intensely shattered and the surface exposure shows signs of devitrification. It is overlain by a white trachyte flow composed of numerous layers ranging in thickness from half an inch to 12 inches, and occasionally interbedded with thin layers or fingers of obsidian 1 inch thick. The intense crumbling of the trachyte and its rapid variation in dip near this locality, together with the shattering of the obsidian, indicate an uplift of some magnitude subsequent to the outpouring of the obsidian and the trachyte as lava flows. Underlying the obsidian is a pale-brown volcanic breccia consisting of lapilli and bombs of lava and obsidian in a matrix of volcanic ash. The west slope of this northward-trending hill is mantled with fragments and chips of glassy jet-black obsidian showing perfect conchoidal fracture, extending all the way to the summit about 350 feet above the road. These obsidian fragments represent the debris from the old Indian workings. A bulldozer cut at the summit shows the fragmental material to be 12 feet thick, and exposes the volcanic breccia to an additional 10-foot depth. The latter contains obsidian bombs 8 inches in diameter. Although now partly filled with debris from the surface, the bottom of the cut is said to have shown solid obsidian in place when first opened. The property is undeveloped to date and has been acquired as a reserve of "popping" obsidian (perlite) for possible use in the manufacture of light-weight aggregate.

About a mile north of Lodi Avenue on the Silverado Trail, in the E½ E½ section 14, obsidian again appears on the west slope of a second northward-trending hill. Here the obsidian has a much lower dip and appears to be over 15 feet thick, lying below the trachyte and above the volcanic breccia, the actual outcrop being covered by a talus of fragmentary obsidian.

Approximately 1½ miles north of Lodi Avenue the Silverado Trail turns northwestward and here in a road cut the obsidian again outcrops. The obsidian and the overlying trachyte have been compressed into a small anticlinal fold as shown in plate 18*A*. The obsidian is about 10 feet thick at this point and overlies the volcanic breccia.

[16] Heizer, R. F., and Treganza, A. E., Mines and quarries of the Indians of California: California Div. Mines Rept. 40, pp. 304, 315, 1944.

Perlite

A discovery in Napa County of an important structural mineral material known as perlite has recently been made by Professor N. L. Taliaferro and his assistants, who have been mapping the Saint Helena quadrangle in cooperation with the State Division of Mines. Perlite has become commercially important because when suddenly heated, it expands, forming a light, frothy material valuable as lightweight aggregate. Very recently ''expanded perlite'' has been found to have wide commercial use as a lightweight aggregate in plasters, concrete, and in the preparation of building blocks. For the most part deposits of the rock perlite are found at considerable distances from marketing centers. The new discovery in Napa County lies within 2 miles east of the railroad station at Rutherford, 60 miles north of San Francisco, in secs. 32, 33, 34, and 35, T. 8 N., R. 5 W., M.D.

Perlite, like obsidian from which the Indians made many of their arrowheads, is a volcanic glass; but instead of being clear like obsidian, perlite is made up of a mass of tiny spheroids, a texture known as ''perlitic.'' It even contains tiny crystals or phenocrysts of quartz, orthoclase, and plagioclase, which may exceed 20 percent of the rock. In composition, perlite is siliceous or acidic, and contains water; it is derived from the same type of molten magma that forms granite. Perlite is not cooled at depth as is granite, however, but is ejected as lava flows during volcanic eruptions.

In the newly discovered Napa County locality, perlite occurs in flows, which range in thickness from a few tens of feet in the southern end of the deposits to several hundreds of feet at the northern end. At one place the perlite occupies a shallow trough or syncline trending northwestward. In another area the bodies of perlite dip steeply toward the southwest and form the west limb of an anticlinal fold, also trending northwestward. The perlite lies upon tuffs and conglomerates, and is overlain by other tuffs and a volcanic rock known as dacite. These rocks form a part of a whole series of volcanics in Napa and Sonoma Counties known as the Sonoma volcanics, of Pliocene age.

The valuable commercial product ''expanded perlite'' used as lightweight aggregate can be made from the natural rock perlite by subjecting it to temperatures between 1400 and 2500° Fahrenheit. ''Expanded perlite'' resembles natural pumice, but is considered to be a superior product for lightweight aggregate. Though ''expanded perite'' can be made from some obsidians, (also found in this area, especially prominent on Glass Mountain) natural perlite rock is considered a better raw material, because this type will sometimes expand as much as 20 times its original size.

There are two occurrences of perlite on Highway 29, about 5 miles east of Napa. One is in a roadcut on the edge of the Basalt Rock Company's Mount George pumice deposit, and the other may be seen in the roadside about half a mile east of the first occurrence. The latter is a thin low-dipping bed less than a foot thick. Although these occurrences may not be of commercial importance they indicate that detailed geological examination of the area overlain by the Pliocene volcanics may disclose additional deposits of commercial value.

Petroleum

Several seepages of oil and gas in the steeply dipping beds of the Knoxville series in Berryessa Valley were noted as early as 1904 and two wells drilled at that time obtained showings at shallow depths. Laizure[17] has reported the activities of the Griffiths Oil Company and other operators in this area. The former company obtained a high-gravity paraffin-base oil at shallow depth from a well capable of producing half a barrel per day. In Division of Mines Bulletin 118, Anderson [18] has prepared a geologic map, two cross sections, and a geologic report on oil in Berryessa Valley. In the same publication may be found tabulated data on all the wells drilled in this area between 1904-39.

Pumice

Pumice is a highly vesicular glass, a glass froth. It is produced by the expulsion of water vapor through the relief of pressure as magma approaches the surface through a volcanic vent. Pumice usually occurs as the upper part of acid volcanic flows, or as fragments among the explosive material thrown out of volcanos. The latter is the mode of occurrence in Napa County, a pumiceous tuff. It is part of a great thickness of volcanic rocks, ranging from basalt at the base, up through scoria, agglomerate, breccia, vitrophyre, tuff, and trachyte, collectively known as the Sonoma group.[19]

All the tuff in this group is not pumiceous. Variation from tuff entirely barren of pumice fragments to tuff completely composed of pumice fragments separated only by thin shells of clay can be seen. This group of volcanic rocks has a wide lateral distribution, and is well exposed east of Napa along Highway 37 on the west slope of the Howell Range where a general southwest dip of about 15° prevails. The pumice members of the group are being mined here, where an excellent road permits easy access to the deposits. At many points in this area the overlying hard cover of trachyte has been removed by erosion and the necessity of stripping is thereby eliminated.

All the present workings are open cuts. The milling operations consist of grinding to free the pumice particles, washing to eliminate the impurities, and drying to remove excess moisture. The sequence of these operations is subject to variation depending on the amount of impurities present and the demands of the individual producer's market. Most of the Napa pumice is used in the manufacture of precast building blocks and as a light-weight aggregate in concrete.

Basalt Rock Company Pumice Deposit

Location: NW¼ sec. 24, T. 5 N., R. 4 W., M. D. (projected).

Owner: Basalt Rock Company, Incorporated (see under *Stone Industry*).

The Basalt Rock Company worked a massive deposit of pumiceous tuff just west of the present rock quarry from 1934-46. This deposit consists primarily of small fragments of pumice imbedded in a matrix of volcanic tuff. Lapilli of other volcanic material such as scoria and obsidian, and bombs of basalt, are also present.

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[17] Laizure, C. McK, Oil possibilities in Berryessa Valley: California Div. Mines Rept. 18, pp. 608-610, 1922.

[18] Anderson, F. M., Berryessa Valley: California Div. Mines Bull. 118, pp. 616-618, 1943.

Tabulated data on wells drilled outside of the principal oil and gas fields: California Div. Mines Bull. 118, p. 651 [Napa County], 1943.

[19] Dickerson, Roy E., Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles: California Acad. Sci. Proc., vol. 11, no. 19, p. 551, 1922.

The quarry face is semi-circular in shape and reaches a height of 75 feet at the center of the deposit. The face is about 600 feet long. Shovels loaded trucks which hauled the material a few hundred feet to crude bins. The crude was run through a hammer mill to storage bunkers. From storage the crude passed through a screw feeder to an oil-fired rotary drier in circuit with a cyclone dust collector. The dried pumice was then pulverized in a ball mill and sacked in 100-pounds bags. This plant had a capacity of 40 tons per 8-hour day.

This quarry is not now in operation, as the company has located a higher grade of pumice at their King deposit on Mount George. The plant is being reconditioned to produce ground pumice from stockpile pumice aggregate.

Basalt Rock Company Mount George (King) Pumice Deposit

Location: SE¼ sec. 24 and NE¼ sec. 25, T. 6 N., R. 4 W., M. D., about 4½ miles northeast of Napa on Highway 37.

Owner: Basalt Rock Company, Incorporated (see under *Stone Industry*).

The Basalt Rock Company Mount George pumice deposit of about 42 acres was acquired in 1939 as a captive deposit to build up reserves for light-weight building blocks. It occupies a small hill rising from an elevation of 400 feet at the highway entrance to the quarry floor, to an elevation of 550 feet at the summit. A massive deposit of pumiceous breccia, it consists of fragments of pumice oriented in all directions, averaging one-half to three-quarters of an inch in diameter, but in some instances, much larger in size. These fragments are separated by thin films of tan-colored clay. Imbedded in this matrix of fragmentary pumice are fragments of foreign material ranging from black obsidian pebbles of lapilli proportions (¼-1½ inches) to black basalt bombs 3 feet in diameter. Fragments of red volcanic scoria 1 inch to 2 inches in diameter are also present.

Quarrying operations began in 1946. Brush, mainly manzanita, was removed with a grubber. By means of a bulldozer and a carryall the top of the deposit was converted into a plane surface sloping southwest. Two Caterpillar diesel D-8 scrapers begin at the east edge of this plane and working side by side proceed in a southwesterly direction, their blades loosening and accumulating a load of pumice which is delivered to a truck-loading bin at the west edge. A rooter is used to dig and loosen the surface when it is wet and soggy, and a ''sheep-foot'' roller breaks over-size chunks. The bin consists of a grizzly of 3-inch pipe set with 9-inch openings overlying a delivery hopper. The oversize is sledged, and the undersize is loaded to a fleet of trucks which haul to the pumice-washing plant or crude stockpile about 8 miles away.

At the washing plant the trucks dump onto a 12- by 12-foot grizzly of 3-inch pipe set with 9-inch openings over a chute leading to a company-designed hammer mill. This primary crusher makes a reduction to minus 3-inch fragments, which are delivered to an inclined conveyor belt about 100 feet long. The belt feeds a Traylor vibrating screen operating under a continuous-pressure multiple water spray. The pressure spray removes the tan clay as waste, which is run to a settling pond. The oversize, plus 2¼ inch, is separated by a top scalping screen and returned by inclined belt conveyor to a second hammer mill for regrinding. The secondary's product is reconveyed to the screen and falls to the bunker as pumice

aggregate. The size of this washed product is plus 8 mesh to minus $\frac{5}{16}$ inch, and it is delivered either to the block plant, the grinding mill, or to the adjoining stockpile. Neither crude pumice nor pumice aggregate is placed on the open market.

Cicero Pumice Quarry

Location: SE¼ sec. 24, T. 6 N., R. 4 W., M. D., 4¼ miles northeast of Napa station on Highway 37.

Owner: Frederica A. Pearl, Napa; leased to C. Cicero, 849 South Jefferson Street, Napa.

The Cicero pumice quarry is on the southeastern slope of a southwestward-trending finger ridge in the western foothills of the Howell Range at an elevation of about 275 feet. The deposit is a pumiceous tuff near the surface, and grades downward into a massive pumice containing some volcanic fragments. The surface layers dip about 20° SW. and show the following changes:

Section near center of pumice pit

Description	Estimated thickness
Chocolate brown surface soil, mud, fragments	1–2 feet
Fragmental pink pumice with brown clay coatings	18 inches
Fragmental gray pumice in gray pumicite matrix	4 inches
Fragmental pink pumice, brown clay coatings	3 feet
Gray pumice with obsidian pebbles	4 feet
Fragmental pink pumice, brown clay coatings	8 inches
Massive gray pumice, some ash and obsidian pebbles	20 feet

It is reported that the floor of this quarry was drilled, showing massive gray pumice to a depth of 80 feet.

This is a captive deposit which supplies the raw material used in manufacturing light-weight building blocks and acoustical plasters. Crude pumice is hand picked, hand loaded, and trucked 200 feet to a hopper at the intake end of the electrically operated plant. A belt conveyor transports the pumice to an inclined Madison No. 147 rotary dryer fired by a Ray oil burner, where the moisture is removed preparatory to grinding. A bucket elevator and a conveyor belt combine to move the dried product to a Williams crusher and pulverizer where the reduction is effected. A second elevator moves the crushed pumice to the surface of a 3-tier, 2- by 6-foot, vibrating screen which grades three products and passes them to the underlying bunkers. These products are: plus 20—minus 14 mesh, plus 14 mesh—minus $\frac{3}{16}$ inch, plus $\frac{3}{16}$—minus $\frac{3}{8}$ inch. Any plus $\frac{3}{8}$ inch is classed as oversize and returned for regrinding.

When blocks are being made the required bunker products are delivered by chute to a conveyor belt set in series with a second conveyor belt normal to it. The second belt deposits the aggregate in a bin overlying the mixing machine. Here sand and/or cement is added, mixed, and dropped by chute into a skip which elevates the mixed batch to the hopper set above the Stearn joltcrete block-making machine. The finished blocks are removed to the drying yard for 30 days. A steam plant is being installed which will pre-cure the blocks and give the plant a capacity of 2500 blocks per day.

The finished standard-size 8- by 8- by 16-inch block weighs about 28 pounds, is said to test over 1100 pounds per square inch and to have excellent fireproof and acoustical qualities. Six men are employed in these operations.

A, OBSIDIAN FLOW EXPOSED ON SILVERADO TRAIL
Light-colored trachyte overlies black obsidian. Obsidian overlies tuff shown at extreme right. About 2 miles north of Lodi Avenue.

B, BASALT ROCK COMPANY, INC.
Mining pumice with diesel scrapers on Mount George.

7—81650

A, BASALT ROCK COMPANY, INC.
Truck-loading chute for pumice on Mount George.

B, BASALT ROCK COMPANY, INC.
Fine grinding pumice plant.

A, WILSON PUMICE QUARRY
Operated by Lava-Lite Products Company.

B, BASALT ROCK COMPANY, INC.
Rock quarry.

A, BASALT ROCK COMPANY, INC. LOADING CAPROCK AT QUARRY FACE

B, BASALT ROCK COMPANY, INC. SCREENHOUSE AND ROCK-CRUSHING PLANT

Pearl Pumice Quarry

Location: S½ sec. 24, T. 6 N., R. 4 W., M. D., 4½ miles northeast of Napa station on Highway 37 and a quarter of a mile north of the highway. Elevation about 200 feet.

Owner: Frederica A. Pearl, Napa. Operator, John Pearl.

The Pearl pumice quarry is a pit on the north side of the ridge on which the Cicero plant is located. On the ridge between the two pits are outcrops of vesicular rhyolite. Patches of manzanita and scattered scrub oaks are common. The face of the pit is approximately 25 feet high by 40 feet long. At the surface the soil overburden reaches a maximum of 2 feet. The soil grades downward into a pumiceous tuff containing tuff fragments half an inch in diameter, separated by films of tan clay. This part of the face is blue gray when wet, but on drying weathers to brownish white. Here, fracturing is common, possibly the result of blasting. This tuff passes downward into good gray massive pumice at the floor level.

A small crushing and screening plant not now in operation is on the property. The pumice was hand picked at the face and drawn by anchor-type dragline scraper about 40 feet to a grizzly with 12-inch openings set over a Bennett crusher run by a 4-cylinder Dodge gasoline engine. The lump pumice was passed to a nearly vertical bucket elevator about 50 feet long, which discharged to an inclined wire mesh trommel screen. The screen has $\frac{1}{4}$-, $\frac{1}{2}$-, and $\frac{3}{4}$-inch openings overlying the respective bunkers. The oversize was discharged off the end of the screen to a dump and returned for regrinding. The operator of this property sold crude or screened pumice.

Silva Pumice Quarry

Location: East part of sec. 20, T. 6 N., R. 3 W., M. D., about 6¾ miles northeast of Napa on Highway 37 at an elevation of 1050 feet.

Owner: William Silva, Napa; leased to Pumice Building Materials Company, Roseville; O. Wright and A. Wilder, lessees.

The road bank at the entrance to the Silva pumice quarry shows a thickness of about 15 feet of massive clean gray pumice with some fragmentary pebbles of ash and obsidian. Mr. Silva has drilled the quarry floor to an additional 5 feet with a hand auger. About 2 acres of this 115-acre property have been cleared and leveled for digging and loading operations. In some places a hard overburden of lava about 2 feet thick has slowed scraping operations.

The pumice is removed with a crawler-mounted P and H 400 excavator and trucked a short distance to a Cedar Rapids 12- by 36-inch jaw crusher. From the crusher is it reloaded and trucked to the plant at Roseville. Operations are conducted only in dry weather as the wet pumice clogged the crusher. About 400 tons were mined in 1946.

Walker Pumice Quarry

Location: NW¼ sec. 20, T. 6 N., R. 3 W., M. D., about 6 miles northeast of Napa station on Highway 37 at an elevation of 1000 feet.

Owner: D. C. Walker, Napa; leased to Messrs. Rice, Bergum, and Pankost, Sacramento, in two separate pieces totaling 67 acres.

The Walker deposit is a gray pumiceous tuff containing lapilli of ash, basalt, and obsidian. This property was leased in September 1946, after which clearing and leveling operations began with a caterpillar thirty-diesel scraper. Special wear-resisting teeth were welded onto the digging

blade in order to move more resistant spots where bombs and lapilli of volcanic material were imbedded in the pumice. A jaw crusher and screen are on the premises for reducing the pumice to minus 1 inch. The pumice aggregate is then loaded with a Wagner Scoopmobile and trucked to Sacramento for use in the manufacture of cellular cement products. These operations are suspended in wet weather owing to clogging of the crusher.

Wilson Pumice Quarry

Location: NE¼ sec. 19, T. 6 N., R. 3 W., M. D., about 5½ miles northeast of Napa on Highway 37 at an elevation of 800 feet.

Owner: T. D. Wilson, 2751 Monticello Road, Napa; leased to Lava-Lite Products Company, D. G. Saunders, manager, 209 12th Street, Vallejo.

Operations began at the Wilson pumice quarry early in 1946 on a side-hill exposure over an area of about 2 acres. The quarried material is locally called "black pumice" but actually is a black volcanic scoria probably representing the surface of a basalt flow. Lateral variations from black scoria to black volcanic mud containing fragments of scoria up to 3 inches in diameter can be seen. Fragments of ropy vesicular lava are also present. The scoria is exposed over a vertical distance of about 35 feet. It is overlain by a bed of light-colored volcanic tuff containing a few gray pumice fragments averaging about an eighth of an inch in diameter. This tuff is about 30 feet thick and is itself overlain by a tuff containing pumice fragments half an inch in size. The latter tuff is seen at the north edge of the quarry near the property line.

A bulldozer delivers the minus 9-inch crude scoria to a wooden hopper. Oversize is sledged by hand. The hopper feeds the conveyor belt of a portable Owa one-piece screening plant operated by a Caterpillar sixty-five diesel engine. The screening plant flow sheet begins at the 25-foot inclined conveyor belt transporting to a 1-inch vibrating screen. The oversize passes to a 10- by 36-inch Cedar Rapids jaw crusher. The screen undersize and the crusher product pass by chute to rolls where the final reduction is made to minus ⅝-inch. The rolls discharge their product to a 50-foot inclined conveyor belt (normal to the first conveyor belt) which transports the aggregate to a truck-loading bunker or stockpile. The stockpile material is loaded to trucks with a Wagner Scoopmobile. The end product is sold as an aggregate for manufacturing lightweight building blocks. Building blocks made of this aggregate have a smooth, straight fracture. They are said to have high compressive strength and low water absorption.

Other Properties

In addition to the active developments mentioned above pumiceous tuff also occurs on other properties along Highway 37 including those of Peter Gasser, Leo Peltenburg, and the Madrone Gun Club.

Quicksilver

Quicksilver has contributed more to the value of Napa County production than any other mineral. Production figures were first recorded in 1862 and some quicksilver has been produced every year since that time, although the annual production in recent years has never approached the yearly output from 1862 to 1909. Signs of exhaustion appeared in the high-grade ore bodies near the end of the latter period and production dropped sharply. Since that time output has been periodically increased under the stimulus of higher unit prices during

periods of economic stress. When the stress is relieved, the price falls and production recedes. The intimate relationship between unit price and production is revealed in a chart prepared by the author for Dolbear's economic report.[20] This chart was drawn for the state as a whole, but it closely approaches the county relationship.

Detailed geological reports on the Knoxville and Mayacmas quicksilver districts of Napa County have been written by Averitt,[21] and Yates and Hilpert.[22] These reports discuss the geology at the individual mines as well as the geology of the district and are extensively illustrated by surface and underground maps, geological sections, block diagrams and charts. A map prepared by Jenkins,[23] shows the relation of the Napa County deposits to the adjoining counties into which they extend.

Aetna Quicksilver Mines Consolidated[24]

Location: Secs. 2 and 3, T. 9 N., R. 6 W., M. D., about 1 mile west of Aetna Springs.

Owner: Ownership is vested in the Basin Montana Tunnel Company, New York City (A. A. Ryan, president; Gerald Sherman, vice president and general manager), and G. I. Barnett, Berkeley.

The J. F. Knapp Corporation, Oakland, leased and operated the Aetna Quicksilver Mines, Consolidated, property from 1938-42. During this period mining operations were conducted both on the surface and underground. The old-dump and open-pit ore was handled with power shovel, tractor, and truck. About 10 men were employed. The ore was treated in the 4- by 65-foot rotary furnace rated at 60 tons.

The present owners acquired the Knapp lease (now expired) in 1942. They produced a moderate amount of ore from the west Pope tunnel in 1943. They also reopened and reconditioned the 4000-foot No. 9 adit leading to the Silver Bow dike. An old stope fill of 5- to 15-pound ore was uncovered but not removed. Numerous thin seams of cinnabar were found in the Silver Bow dike, and in the sandstone at the hanging wall of the dike. On expiration of government contracts early in 1945, the mine was closed and a watchman placed on the premises. The office, shop, and bunkhouse buildings are in good condition.

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[20] Dolbear, S. H., Economic mineral resources and production of California: California Div. Mines Bull. 130, p. 193, 1945.

[21] Averitt, Paul, Quicksilver deposits of the Knoxville district, Napa, Yolo, and Lake Counties, California: California Div. Mines Rept. 41, pp. 37-44, 1945.

[22] Yates, Robert G., and Hilpert, Lowell S., Quicksilver deposits of eastern Mayacmas district, Lake and Napa Counties, California: California Div. Mines Rept. 42, pp. 231-286, 1946.

[23] Jenkins, Olaf P., Economic mineral map of California no. 1, quicksilver, scale 1:1,000,000, California Div. Mines, 1939.

[24] Yates, R. G. and Hilpert, L. S., op. cit., pp. 254-259, 1946.
Ross, C. P., Quicksilver deposits of the Mayacmas and Sulphur Bank districts California: U. S. Geol. Survey Bull. 922-L, p. 346, 1940.
Ransome, A. L. and Kellogg, J. L., Quicksilver resources of California: California Div. Mines Rept. 35, pp. 404-407, 1939.
Averill, C. V., op. cit., p. 227, 1929.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, pp. 77-79, 1918.
Bradley, W. W., Mineral resources Napa County: California Min. Bur. Rept. 14, pp. 284-286, 1913.
Forstner, Wm., Quicksilver resources of California: California Min. Bur. Bull. 27, pp. 72-76, 1903.
Mathyas, F. C., Mineral resources Napa County: California Min. Bur. Rept. 13, p. 597, 1895.
Preston, E. B., Mineral resources Napa County: California Min. Bur. Rept. 12, p. 362, 1894.
Fairbanks, H. W., Notes on the geology and mineralogy of portions of Tehama, Colusa, Lake and Napa Counties: California Min. Bur. Rept. 11, p. 72, 1892.
Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mon. 13, pp. 371-374, 1888.
Raymond, R. W., Statistics of mines and mining in states and territories west of the Rocky Mountains, vol. 6, p. 31, 1874.

Aetna Extension[25]

Location: Sec. 34, T. 10 N., R. 6 W., M. D.
Owner: Formerly Atkins-Kroll Company, San Francisco.

A large amount of surface and underground exploration work involving the expenditure of about $30,000 has been done on the Aetna Extension. During 1941 and 1942 an attempt was made to develop ore in the No. 1 tunnel along the Silver Bow dike of the Aetna mine. This tunnel was extended to the line of the Aetna property. The Aetna Extension has now been abandoned and taxes are no longer being paid on the property. No quicksilver was ever produced.

Bella Oaks Mine[26]

Location: Sec. 20, T. 7 N., R. 5 W., M. D., on the west side of Napa Valley about 1½ miles west of Rutherford.
Owner: Martin Stelling, Rutherford, who purchased the property in 1945.

Bella Oaks mine was acquired by H. W. Gould in 1938 from the Reddington estate. It remained idle until 1942 when F. A. Bachich, St. Helena, leased the property and began sinking a new shaft. A 40-ton Gould rotary furnace was installed late in 1942 to treat mine and dump ore. Development work proved unsatisfactory, the lease was given up late in 1943, and equipment was removed.

Corona Mine[27]

Location: Secs. 32 and 33, T. 10 N., R. 6 W., M. D., about 1¼ miles west of the Oat Hill mine over road which is now impassable.
Owner: Vallejo Quicksilver Mining Company, 525 Capitol Street, Vallejo (c/o O'Hara, Randall, Castagnetto & Kilpatrick).

Unproductive since 1916, the Corona mine was reopened in 1941 under lease to the Twin Peaks Mining Company. Underground operations were through square-set stopes. A new ore body was discovered on the surface east of the old open pit. The ore was trammed to the truck bunker and then trucked about a mile to the mill at the Twin Peaks mine. Here the ore was treated in a Gould-type rotary furnace. It is reported about 15,000 tons of low-grade Corona ore was treated previous to August 1943, when the lease was abandoned.

The remains of a six-pipe retort furnace with six short vertical condensers all connected to one cast-iron settling box, followed by a suction fan discharging into an inclined tile pipe and stack, is standing on the property. Part of the old 50-ton Scott fine-ore furnace is also present.

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[25] Yates, R. G., and Hilpert, L. S., op. cit., p. 259, 1946.
Bradley, W. W., Quicksilver resources in California: California Min. Bur. Bull. 78, p. 80, 1918.

[26] Ransome, A. L., and Kellogg, J. L., op. cit., p. 407, 1939.
Averill, C. V., op. cit., p. 228, 1929.
Bradley, W. W., Mines and mineral resources Napa County: California Min. Bur. Rept. 14, p. 286, 1913.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 80, 1918.
Preston, E. B., op. cit., p. 364, 1894.

[27] Yates, R. G. and Hilpert, L. S., op. cit., pp. 266-267, 1946.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 81, 1918.
Forstner, Wm., op. cit., pp. 79-80, 206-207, 1903.
Mathyas, F. C., op. cit., p. 597, 1895.

Enterprise Engineering Company

The Enterprise Engineering Company (president, R. Lee Cates; general manager, Henry Ott; last known address 1706 Broadway, Oakland) was incorporated as a California corporation on February 18, 1944, with an authorized capital of 50,000 shares of stock of no par value. Leases were acquired on parts of the Ink Ranch, including part of the channel of lower James Creek. A camp was established in sec. 1, T. 9 N., R. 6 W., M. D., about 1½ miles east of Aetna Springs.

The company proposed to recover cinnabar from the gravels of James Creek, using a dragline shovel and floating dredge operated on diesel power.

This equipment was duly installed and operated for a time in sec. 6, T. 9 N., R. 5 W., where boulder tailings line the creek banks for four-tenths of a mile over an area estimated to be about 5,000 square yards. The equipment was removed in late 1946, according to local reports in Pope Valley. On July 24, 1945, the company made further application to issue an additional 10,354 shares of stock for the purpose of converting to electric power and installing a 20-ton furnace.

As far as could be determined, no furnace equipment was ever installed. A pile of ''concentrate'' from the dredging operations was seen at the camp where the buildings remain. This ''concentrate'' consists of an estimated 10 to 15 cubic yards of sand. A sample was obtained and panned, and showed a trace of cinnabar. The sample was later assayed by Abbott A. Hanks, Inc., San Francisco, and found to contain 0.13 percent mercury or 2.6 pounds of mercury per ton of sand ''concentrate''. During the war years when the price of mercury ranged from $175.00 to $184.00 per flask, the experienced operators considered 0.25 percent ore, 5 pounds of mercury per ton of ore, the lowest grade which could be worked at a profit.

Over a period of 30 years beginning in 1915, quicksilver production has been reported from the placers of James Creek to the extent of nearly 330 flasks. In view of this fact it should be pointed out that all this productoin has been obtained in secs. 34 and 35, T. 10 N., R. 6 W., M. D., along the upper part of James Creek where its course is through the hills and its gradient a minimum of 150 feet per mile. Throughout this part of its course, the creek is fed during the rainy season by numerous tributary streams traversing old mine dumps and cinnabar-bearing outcrops. In this way concentration of fine particles of cinnabar sand occurs in James Creek itself whose bed is comparatively narrow at this point. At the east line of section 35, James Creek discharges onto an alluvial flat which is the northwest end of Pope Valley. Here the stream gradient drops from 150 feet per mile to 12½ feet per mile, which gradient it maintains to the point of the Enterprise dredging operation about 2 miles to the southeast. Furthermore, the width of the stream bed increases at its entrance into Pope Valley from a comparatively narrow thread to a potential width of nearly a mile. Consequently, as James Creek enters Pope Valley, its transporting power is decreased and its contents are no longer concentrated in a narrow bed but disseminated over an extremely wide area. In addition, its contents are further diluted by contact with other incoming streams from adjoining hillsides barren of cinnabar. These factors combine to reduce the grade of cinnabar concentration in the Pope Valley alluvium to the point of uneconomic operation.

Ivanhoe Mine[28]

Location: SE¼NE¼, the N½SE¼, and part of the NE¼NE¼ sec. 33; S½NW¼, S½NE¼, N½SW¼, N½SE¼, and part of the NW¼NW¼ sec. 34; S½NW¼ and the N½SW¼ sec. 35, T. 10 N., R. 6 W., M. D. The underground workings of the Ivanhoe are in the N½SE¼ sec. 34, T. 10 N., R. 6 W., M. D.

Owner: Paul Piner and Cooper, Calistoga, who purchased the property from Harry Patten in 1942.

The above-mentioned area, comprising slightly more than 600 acres, follows the course of James Creek from the Oat Hill dumps to its point of discharge into Pope Valley. It is a narrow strip 2 miles long running eastward and averaging a quarter of a mile both north and south of the creek. It is from this area that much of the James Creek placer cinnabar has been recovered. The creek gravels are run through concentrating machines and the concentrate is retorted. A small production was reported from 1939-42 inclusive.

Knoxville Mine[29]

Location: Secs. 6 and 7, T. 11 N., R. 4 W., M. D., about 48 miles north of Napa on Highway 37.

Owner: George E. Gamble, 1431 Waverly Street, Palo Alto.

The Knoxville mine was reopened in December 1939 by the owner, George E. Gamble, after nearly 3 years of inactivity. Operations were begun on the old low-grade ore dumps, old creek gravels, and an open pit. Equipment consisted of a bulldozer for stripping and prospecting, and a power shovel for loading to dump trucks, which hauled the ore about half a mile to the mill.

The mill flow sheet begins with a cylindrical steel bunker (about 6- by 6-foot) with a conical bottom; thence the ore passes by chute to jaw crusher discharging onto a covered inclined belt conveyor about 80 feet long. The belt conveyor elevates the crushed ore to a trommel screen atop an ore bin feeding the furnace. Final feed is about 1 inch. The furnace is a Gould rotary 5- by 40-foot with a countercurrent feed rated at 40 tons daily capacity. Dust is removed by a cyclone dust collector, and vapors are conducted through 18 cast-iron condensers, pass through two redwood settling tanks, then through redwood pipe 50 feet long to stack. Mill tailings are hand trammed about an eighth of a mile to the dump. Ten men were employed in 1942-43. Operations were suspended in October 1944. The property was then leased by Mr. Gamble to Hickox and Wilson, who continued mining the bottom of the open pit, sorting, and retorting the ore.

In March 1945 the mine was leased to A. G. Truitt (Gamble's millman), J. F. Carr, and A. Cerar. These lessees operate the property as an

[28] Yates, R. G., and Hilpert, L. S., op. cit., p. 259, 1946.
Ransome, A. L., and Kellogg, J. L., op. cit., p. 408, 1938.

[29] Averitt, Paul, op. cit., p. 80, 1945.
Ransome, A. L., and Kellogg, J. L., op. cit., p. 409, 1939.
Averill, C. V., op. cit., p. 230, 1929.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, pp. 82-84.
Bradley, W. W., Mineral resources Napa County: California Min. Bur. Rept. 14, p. 387, 1914.
Forstner, Wm., op. cit., pp. 76-79, 1903.
Mathyas, F. C., op. cit., p. 599, 1895.
Preston, E. B., op. cit., p. 363, 1894.
Fairbanks, H. W., op. cit., pp. 69-71, 1892.
Becker, G. F., op. cit., pp. 284-290, 1888.
Raymond, R. W., Statistics of mines and mining in states and territories west of the Rocky Mountains, vol. 8, p. 20, 1876 . . . . vol. 7, p. 175, 1875 . . . . vol. 6, pp. 21, 64, 1874.
Egleson, Thomas, Notes on treatment of mercury in north California: Am. Inst. Min. Met. Eng. Trans., vol. 3, pp. 279-286, 1874.

open pit. Stripping is necessary to reach the level of the ore and old workings. In some instances as much as 35 feet of overburden must be removed. The floor of the pit is now down to the level of the old discovery tunnel. The operators work 18 hours a day over a 5-day week and run the mill near capacity during this time. The ore is said to run 5 to 6 pounds of quicksilver per ton.

The mining equipment includes a caterpillar D-6 scraper, a Bucyrus-Erie two-wheel 5-cubic-yard scraper, a $\frac{5}{8}$-cubic-yard Insley loading shovel, and a dump truck. The haul to the mill is about half a mile.

La Jolla Mine[30]

Location: Sec. 24, T. 7 N., R. 6 W., M. D., about 6 miles west of Oakville.

Owner: H. W. Gould and Company, San Francisco.

In 1939 La Jolla mine was leased to F. A. Bachich, Saint Helena, who produced a small quantity of quicksilver from the property, treating the ore in a rotary furnace. He gave up the lease at the end of the year. No further production has been recorded to date. All buildings and equipment have been removed. The tunnel entrance is partly caved and filled with 2 feet of water. The road to the mine is below average but passable.

Manhattan Mine[31]

Location: NW$\frac{1}{4}$ sec. 6, T. 11 N., R. 4 W.; N$\frac{1}{2}$ sec. 1, T. 11 N., R. 5 W.; SW$\frac{1}{2}$ sec. 36, T. 12 N., R. 5 W., M. D.

Owner: Manhattan Quicksilver Mines Company, R. B. Knox, president. Leased to Charles Wilson and W. N. Hickox.

A small production was reported from this mine during 1944 and 1945. No activity was in evidence at the time of visiting the property in January 1947. A one tube D-retort and part of the old Knox fine ore furnace remain on the premises.

Oat Hill Mine[32]

Location: Secs. 27, 28, 33, and 34, T. 10 N., R. 6 W., M. D., about 9 miles southeast of Middletown.

Owner: Norman B. Livermore, 216 Pine Street, San Francisco.

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[30] Ransome, A. L., and Kellogg, J. L., op. cit., p. 410, 1939.
Averill, C. V., op. cit., p. 239, 1929.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 84, 1918.
Forstner, W., op. cit., p. 80, 1903.

[31] Averitt, Paul, op. cit., pp. 82-84, 1945.
Ransome, A. L., and Kellogg, J. L., op. cit., p. 411, 1939.
Averill, C. V., op. cit., p. 235, 1929.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 86, 1918.
Bradley, W. W., Mineral resources Napa County: California Min. Bur. Rept. 14, p. 288, 1913.
Forstner, Wm., op. cit., pp. 81-89, 1903.
Mathyas, F. C., op. cit., p. 598, 1895-1896.
Preston, E. B., op. cit., p. 363, 1894.
Fairbanks, H. W., op. cit., p. 71, 1892.
Becker, G. F., op. cit., p. 282, 1888.

[32] Yates, R. G. and Hilpert, L. R., op. cit., pp. 261-265, 1946.
Ransome, A. L. and Kellogg, J. L., op. cit., pp. 411-413, 1939.
Averill, C. V., op. cit., pp. 235, 1929.
Boalich, E. S., Mines and mineral resources Napa County: California Min. Bur. Rept. 17, p. 160, 1920.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Rept. 78, pp. 88-90, 1918.
Bradley, W. W., Mineral resources Napa County: California Min. Bur. Rept. 14, pp. 289-291, 1913.
Forstner, Wm., op. cit., pp. 89-91, 1903.
Mathyas, F. C., op. cit., p. 598, 1895-1896.
Preston, E. B., op. cit., p. 364, 1894.
Fairbanks, H. W., op. cit., p. 65, 1892.
Mineral resources Napa County: California Min. Bur. Rept. 8, p. 413, 1888.
Becker, G. F., op. cit., pp. 356-358, 1888.

This property was leased and operated in 1939 by H. W. Gould, who immediately began development operations with 26 men. The costly square set method of mining was gradually replaced by top slicing. The ore was hauled from mine to mill and treated in a Gould rotary furnace rated at 90 tons. By 1943 the number of men employed was increased to 45. The contract with Metals Reserve Corporation was cancelled in 1943, and this together with the high labor costs prevailing forced a gradual curtailment of operations. The plant was dismantled in 1945, and equipment removed with the exception of a bank of twelve well-weathered cast iron condensers.

In addition, the Oat Hill dump on the Eureka claim was worked from 1942 to 1946 by A. Garcia of Middletown. Dump tailings were run through a trommel screen, concentrated on a Wilfley table, and the concentrates were retorted. A forest fire raging up the canyon of James Creek has since destroyed all the office and camp buildings. The trommel screen and Wilfley table remain on the property.

Oat Hill Extension Mine[33]

Location: Secs. 27 and 34, T. 10 N., R. 6 W., M. D., adjoining the Oat Hill mine on the east boundary of the latter.

Owner and operator: Zack Anderson, Middletown, Lake County. Mr. Anderson has recently acquired 240 acres including the E½SW¼ and the W½SE¼ of sec. 27, the NE¼NW¼ and the NW¼NE¼ of sec. 34. This area covers the workings of the Toyon mine.

No production has been made here since 1944, at which time Mr. Anderson entered the naval service. He returned to the mine in late 1946 and found all three tunnels caved and the concentrating equipment worn and weathered. He says, however, that a sizeable body of ¼ percent ore remains. This body will be mined by a short adit and a raise to the surface where an open pit scraper will deliver ore to the head of the raise.

A new galvanized iron machine shop and a new mill building of the same construction are being equipped for future operation. The flow sheet will include grinding machinery, jig, and concentrating table. Concentrates will be charged to the retort operating on butane fuel with automatic feed of 10 pounds pressure. During the early war years, 1941-44, this property could produce 12 tons of ore per 8-hour day using a three-man crew. When the property is completely re-equipped the operator hopes to attain a production figure of 40 tons per day.

Toyon Mine[34]

Location: About the NW¼NE¼ sec. 34, T. 10 N., R. 6 W., M. D.

Owner: Zack Anderson, Middletown, who purchased the property in 1946. Formerly leased to Frank Adams, Pope Valley.

A small production of cinnabar from the Toyon mine was reported in 1941 and 1942. Two 12-inch by 6-foot retort tubes were used to recover the quicksilver.

Twin Peaks Mine[35]

Location: Sec. 4, T. 9 N., R. 6 W., M. D., about 2 miles southwest of the Oat Hill mine. This road is impassable at the present time.

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[33] Yates, R. G., and Hilpert, L. S., op. cit., p. 265, 1946.
Ransome, A. L., and Kellogg, J. L., op. cit., p. 414, 1939.
[34] Yates, R. G., and Hilpert, L. S., op. cit., p. 265, 1946.
Ransome, A. L., and Kellogg, J. L., op. cit., p. 415, 1939.
[35] Yates, R. G., and Hilpert, L. S., op. cit., p. 267, 1946.
Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 91, 1918.
Forstner, Wm., op. cit., p. 92, 1903.

Owner: Nathan Fay, et al.; manager, Louis D. Day, 150 Woodland Way, Piedmont.

The Twin Peaks mine, inactive since 1918, was reopened in 1941 by the Twin Peaks Mining Company, who continued operations into August 1943, and reported a small production. Development was carried on by drifting and square set stoping off the Wilson tunnel. The ore was treated in a Gould rotary furnace, only the tube of which remains on the property. This furnace is said to have treated about 15,000 tons of ore from the Corona mine between 1941 and 1943.

Silver

Quartz veins bearing silver sulphides, associated gold, small amounts of copper, and traces of lead, were found on the lower slopes of Mount Saint Helena as early as 1870. These veins are located in a belt extending from sec. 30, T. 9 N., R. 6 W. to sec. 2, T. 9 N., R. 7 W. A number of claims were staked at that time but activity gradually ceased and some are now forgotten. Only two of these claims developed into productive mines, the Silverado and the Palisade. The former, owned by Harry Patten, Calistoga, has been inactive since 1927 and has been described by Averill[36] in his report.

Palisade Mine[37]

Location: Sec. 24, T. 9 N., R 7 W., M. D., 3 miles north of Calistoga at an elevation of about 600 feet.

Owner: Vincent C. Harrison, Calistoga, who acquired the property in March 1944.

The Palisade silver-gold mine was operated in 1929 and 1930 by the Banner Development Company of San Francisco and reportedly shut down in November 1930 owing to lack of water for the mill. A receiver operated the property for a short period in 1931. The mill equipment at that time included Blake crusher, Marcy ball mill, tube mill, Dorr duplex classifier, a six-cell Kraut flotation machine, and an Oliver filter.

No further production was recorded until 1935 when the Coast Range Mining Company, 700 La Brea Avenue, Los Angeles, took over and successfully operated the mine until the latter part of 1938.

In September of that year the Graham Loftus Oil Corporation, 811 West 7th Street, Los Angeles, became the operating company. At that time the Calistoga newspaper reported that a new orebody 125 feet in length, 450 feet in depth, averaging 10 feet in width, was being opened up between the 100- and 600-foot levels. It was further reported to assay "better than $10 per ton" in gold and silver. The ore was treated by flotation and the concentrates were shipped. The proximity of the mine to the Selby smelter (about 50 miles) with consequent low transportation charges made the mining of this low-grade ore possible.

This company mined until January 1941, when Helena Consolidated Mines, Incorporated took over and continued operations until August

[36] Averill, C. V., op. cit., p. 238, 1929.

[37] Averill, C. V., op. cit., pp. 237-238, 1929.
Castello, W. O., Mineral resources of Napa County: California Min. Bur. Rept. 17, p. 159, 1920.
Bradley, W. W., Mineral resources Napa County: California Min. Bur. Rept. 14, p. 270, 1913.
Mineral resources Napa County: California Min. Bur. Rept. 8, pp. 413-415, 1888.
Becker, G. F., op. cit., p. 370, 1888.

of the same year. The mine was closed in August 1941, the buildings and equipment were removed, and the company stated that no further operations were contemplated. Rising wages, migration of miners to defense jobs, rising costs of supplies and materials together with the difficulties of obtaining them, higher taxes and a fixed price for gold, were all factors tending to reduce the margin of profit on this low-grade ore. The mine remains idle to date (January 1947).

Stone Industry

There were formerly a number of small quarries in Napa County which produced sandstone or tuff blocks for bridges and cut-stone buildings. The continually mounting labor costs in the cut-stone industry, and the general acceptance and use of lower-priced concrete construction has nearly eliminated the production of building stone, not only in the county but throughout the state.

''Miscellaneous stone'' is a term used to include crushed rock, sand and gravel, paving blocks, and grinding-mill pebbles. This usage has developed from the fact that an individual operator often produces sand and gravel from a stream bed, using the large boulders as the source of his crushed material. Crushed rock is often further subdivided on a usage basis into macadam, ballast, rubble, riprap, and concrete aggregate, although it is not always possible to determine the final disposition of the product.

Basalt Rock Company, Incorporated[38]

Location: Parts of secs. 22, 23, and 24, T. 5 N., R. 4 W., M. D. (projected); 2½ miles south of Napa on Highway 29, and 1 mile east of the Napa River.

Officers: A. G. Streblow, president; E. Brovelli, secretary; John Anderson, controller; J. Kay, superintendent of block plant; J. F. Cassani, superintendent of rock quarry; Carl Butler, superintendent pumice quarry; Napa, California.

The present rock-quarry operations are being conducted on the lowermost knob of a long northwestward-trending finger ridge of volcanic rock extending out of the southern end of the Howell Range. This knob rises to a height of 500 feet above the valley floor. The rock is part of a basalt lava flow, very dark, dense and tough. There is no overburden. In a few places the soil reaches a maximum of 1 to 2 feet, and here the surface is brushy. The brush is removed with a grubber before blasting.

Ordinarily a quarry face 100 to 200 feet in height is carried, and such was the case in the old quarry about a quarter of a mile east of the present operations. Lack of uniformity, the development of too much scoria, local variations typical of surface flows, and the resultant high cost of sorting and handling, forced the abandonment of that site. At the present time (January 1947) two 40-foot benches are carried and a third bench is being opened. The upper face is about half a mile long, reaching a height of 40 feet near the center, and tapering off to about 15 feet toward the south end. It is traversed by joints in many directions. As a result the rock is ''blocky'' and breaks readily. A persistent horizontal or near-horizontal trend is discernable, which separates the face into layers ranging from 1 inch to 6 feet in thickness, and gives the appearance of bedding when viewed from a distance. No other definite direction of

[38] Averill, C. V., op. cit., pp. 239-240, 1929.

jointing could be determined. Various points along the face provide rocks for several different uses.

The former system of breaking rock through wagon drill holes has been abandoned for the well-drilling method. The holes are drilled vertically by a portable drilling rig of the percussion type, on an even spacing along a line behind and parallel to the face. In this way a relatively vertical free face can be blasted. The size, spacing, and depth of the holes vary with the height of the face blasted. These factors may be subject to a little experimentation until the desired type of fragmentation is obtained. As many as 14 holes have been fired simultaneously, with 20 to 40 percent Trojan explosives, depending on conditions. Usually enough rock is broken down to supply the shovels for 6 weeks.

The rock blasted down is sorted by two shovels, one 5-cubic-yard electrically operated crawler-mounted Bucyrus Erie, and one 3-cubic-yard crawler-mounted Northwest diesel. These shovels stockpile the "caprock" (3- to 8-ton rock with one side flat), and the "face-rock" or "A rock" (1- to 5-ton rock), just below the working level and load the remaining fragments into Euclid end-dump trucks which haul to the crushing plant about a quarter of a mile distant. The trucks carry a maximum load of 15 tons and are equipped with wear-resisting, longitudinally ribbed bottoms. On breakwater contracts the "caprock" and "face-rock" are trucked to the Napa River, transferred to 1000-ton barges by crane, and shipped to the delivery point.

Reduction operations are conducted in a modern electrically operated plant erected about 5 years ago and designed for three-stage crushing. It has a maximum capacity of 2500 tons per 8-hour day. The quarry trucks dump into a 5- by 12-foot Traylor-Sheridan (eccentric) feeder set on a 25° slope feeding a 48- by 60-inch Traylor jaw crusher. This primary crusher discharges a 38- by 42-inch product onto a 48-inch inclined conveyor belt about 25 feet long, conveying to a grizzly over the secondary crusher.

The secondary is a 4-foot Traylor gyratory crusher making a maximum 20-inch product on 30-inch belt conveyor about 250 feet long, discharging onto a 5- by 14-foot double Seco screen. The oversize is returned on a 24-inch belt conveyor to a 3-foot Traylor gyratory crusher set at $1\frac{3}{4}$ inches. This product is reconveyed to the screens on the 30-inch belt where the final products are made and emptied into the bunkers below.

Three end products are produced by the screens, namely: 0- to $\frac{5}{8}$-inch, $\frac{5}{8}$- to $1\frac{1}{2}$-inch, $1\frac{1}{2}$- to $2\frac{1}{4}$-inch. These are standard-sized products and are removed by truck from the bunkers to stockpiles on the premises where reserves of from 20,000 to 50,000 tons are maintained. A standby Niagara screen may be operated above the bunkers whenever special products such as $\frac{3}{8}$- to $\frac{3}{4}$-inch are required.

The bunkers are also the locus of a "pug" mill. This mill consists of a Fairbanks weigher and mixer for making slurry used as a road base beneath asphalt. The slurry is made as required, loaded directly to trucks and hauled to the job under contract.

Power requirements total about 700 horsepower, ranging from 25 horsepower on the conveyor belts to 150 horsepower on the large Westinghouse motor running the primary crusher.

Adjoining the three-stage crusher is a "grizzly plant" capable of making special products as needed. No oversize is produced in this plant,

The large fragments are separated as "B rock" or two-man rock (200 to 2000 pounds), and "Engineers rock" or "one-man" rock (25 to 150 pounds). The balance of the feed is separated by a three-stage 5- by 15-foot inclined rotary screen making products as follows: 4- to 7-inch, $1\frac{1}{2}$- to 4-inch, and minus $1\frac{1}{2}$-inch. The flow in this plant is from quarry truck dumping to inclined chute set with chain feeder and tuning-fork grizzly, then to screen and local bunkers.

Although an attempt is made to concentrate on certain standard products, the reduction plant is designed for a large degree of flexibility and can be adapted to fill the size specifications of any contract. The list of products which the company can supply includes all types of crushed rock, riprap fill material, river sand, plaster sand, ready-mix concrete, building bricks (grade A testing 1000 pounds per square inch, and grade B testing 750 pounds per square inch), natural and reinforced hollow building blocks, and many special contract materials. Shipment can be made by truck, rail, or water.

Building-Block Plant. The Basalt Rock Company, Incorporated, operates a building-block plant about half a mile west of the quarry on the east edge of Highway 29 for the manufacture of concrete and light-weight building blocks, bricks, and other structural shapes both in standard and special contract sizes. The light-weight blocks contain a pumice aggregate and are sold under the trade name "Basalite."

Washed pumice or concrete aggregate from the stockpiles is trucked half a mile and dumped into a 9-cubic-yard hopper at ground level. The hopper empties vertically onto a 200-foot shielded belt conveyor inclined at an angle of 15°. The feed end is set in a small underground room. The aggregate is elevated to bunkers at the top of the plant and drawn into any one or all of three mixing machines where sand and/or cement is added. The mixers discharge into Besser vibrapac block-making machines set vertically below. The blocks are removed on trays to loading racks and transported by "scooters" to the steam curing sheds, where they remain for 14 hours in summer and 24 hours in winter. They are then stacked in the curing yard, where they remain for 28 days. They are then ready for delivery.

One Besser machine turns out 10 standard blocks per minute, and an output of 280,000 blocks per month can be maintained. The standard building block is 8 by 8 by 16 inches, and the light-weight block weighs about 31 pounds. These blocks withstand a pressure of about 1400 pounds per square inch; water absorption is $13\frac{1}{2}$ to $14\frac{1}{2}$ pounds per cubic foot. The present (1947) selling price is $210 per thousand.

Asphalt Plant and Shipyard. Asphalt road mixes are prepared in the asphalt plant of the Basalt Rock Company on the Napa River. A steel-fabricating plant and shipyard adjoins the asphalt plant. During the period preceding the war the company was unable to obtain satisfactory delivery on steel barges. As a result, the steel plant and shipyard were built. In addition to filling their own barge requirements during the war, the company delivered 30 ARS (salvage vessels) and a number of lighters and tankers for the government. Pressure tanks and grubbers are now being built in this plant and a complete list of steel products is being planned. The company maintains an active research department to develop new products and to improve the present line.

Juarez Quarry [39]

Location: SE¼ sec. 11, T. 5 N., R. 4 W., M. D. (projected), approximately 2 miles east of Napa station off Terrace drive on the south side of Tulucay Creek.

Owner: M. L. Reidenback, 1115 Willow Street, Napa.

The Juarez quarry was formerly operated by G. E. Errington and was purchased by the present owner about 1936. Operations are conducted on a small knoll of basalt rock about a quarter of a mile wide and half a mile long, which rises to an elevation of 170 feet. The rock is jointed along planes approximately horizontal and cross jointed in various directions. There is no brush or overburden but a thin clay soil penetrates the joint planes at many points, especially near the surface. Variations from fresh rock to highly altered material are seen. The fresh rock is usually more massive and breaks into large fragments 2 feet in diameter suitable for riprap. The jointed areas are usually more weathered, the degree of alteration having in some places led to abandonment of the working face. The slightly altered material is most suitable as feed to the crushing plant.

The hill has been worked as a series of disconnected benches. Five different levels with 25-foot faces are discernable. Present work is on the highest bench. The face is blasted with 40 percent explosives and fired electrically.

The broken rock is loaded with a ⅜-cubic-yard crawler-mounted shovel and hauled by truck to the coarse-feed bin where the plus 12-inch is hand sledged and the minus 12-inch passes through a grizzly to a 12- by 36-inch Cedar Rapids primary crusher. The crusher discharges to a 1½-inch vibrating screen. The undersize is caught by a belt conveyor and carried to the 1-inch stockpile; the screen oversize is passed through a 32-inch Tel-Smith cone crusher. The plus ¼-inch from the secondary crusher is lifted by bucket elevator to the top of the mill house and emptied onto a graduated screen set over the bunkers. This screen makes three products: birdseye, ¼- to ½-inch; inch rock, ½- to 1-inch; and 2-inch rock, 1- to 2-inch. The minus ¼-inch products from the secondary crusher are discharged to storage as dust, and sand. Maximum production is 150 tons per 8-hour day. Four men are employed. These products are sold chiefly for use in the Napa County road system, as the county no longer maintains its own quarry and crushing plant.

S. Lenz and Son Basalt Quarry and Plant

Location: SE¼ sec. 22, T. 8 N., R. 6 W., M. D., about 2¼ miles northwest of Saint Helena on Highway 29 and half a mile west of the Southern Pacific railroad.

Owner: W. J. Lenz, Saint Helena.

Mr. Lenz operates a plant manufacturing concrete building blocks and other concrete products on part of the 107-acre tract owned by him. The basalt quarry on the premises is no longer worked. It has become more economical to buy graded river sand and aggregate from the Basalt Rock Company. Special-purpose sands are "imported" from Felton in Santa Cruz county and other localities.

The plant consists of raw-material bins, mixing machine, tamping machines, vibrating machine, steam-curing sheds and curing yards. Six men are employed during the winter season, and the possibility of expanding the force during the summer is very good. Among the more important concrete products manufactured are: building blocks, culverts, drain pipe, irrigation pipe, sewer pipe, and septic tanks.

[39] Averill, C. V., op. cit., p. 240, 1929.

McGill Rock and Sand Company

Location: NE¼ sec. 23, T. 7 N., R. 5 W., projected, on Conn Creek and Skellinger Lane, about 1½ miles east of Oakville.

Owner: H. W. and T. F. McGill, 602 Florida Street, Vallejo.

The McGill plant began operating in 1929 and was acquired by the present owners in 1932. The creek gravels are loaded to dump trucks by an Insley crawler-mounted clamshell bucket. The truck haul to the screening plant is about 2 miles. The trucks dump to a bin feeding a vertical bucket elevator which discharges to a revolving screen. Here the feed is sprayed and screened. All products except the sand pass directly to the underlying storage bunkers. The sand is removed by a screw conveyor to an adjoining bunker. The screen oversize is carried by chute to a recently installed Straub jaw crusher. The crusher discharges to a chute which returns the crushed material to the elevator. The products usually made are 1¼-inch rock, pea gravel, and sand. On special orders such products as 2¼-inch rock can be produced by suitable screen adjustments. This plant is wood construction and is electrically operated by a 30-horsepower motor.

Roderick Sand and Gravel Pit

Location: NE¼ sec. 34, T. 6 N., R. 4 W., M. D. (projected), about 2¾ miles north of Napa on the Napa River.

Owner: W. M. Roderick, Trancas Avenue, Napa.

Mr. Roderick has operated intermittently for 23 years digging gravel, sand, and loam, from the river bars built up during periods of high water over an extent of about half a mile. These miscellaneous stone products are selectively loaded to trucks by a Caterpillar D-4 loader. At one time a screening plant existed on the property, but this was washed down stream during a period of high water. Present production is about 350 cubic yards per month, which is sold by order as fill material. Two men are employed in this work.

Smith Gravel Pit

Location: SW¼ sec. 31, T. 8 N., R. 5 W. (projected), on Sulphur Creek about a quarter of a mile southwest of Highway 29, and a quarter of a mile southeast of Spring Street, Saint Helena.

Owner: Harold V. Smith, 1361 Main Street, Saint Helena.

A new washing and screening plant has been built to produce graded aggregate from the creek gravel. A scraper moves the gravel to a bin set over a 100-foot inclined belt conveyor which discharges its load onto the bed of a three-decked 4- by 8-foot shaking screen. A water spray removes the clay and fine dirt. The screen separates four products, namely: plus 1¼ inch (oversize); minus 1¼ inch to plus ¾ inch; minus ¾ inch to plus ⅜ inch; and minus ⅜ inch, or sand. The oversize is carried by chute from the top screen to a Telsmith 2-H reduction crusher driven by a six-cylinder gasoline engine. The crusher product is discharged onto a second inclined conveyor belt about 60 feet long travelling counter to the first belt. This second belt terminates at a chute set normal to the conveyors, where the load is transferred back to the original belt and screened. The intermediate screen products are moved by chutes to compartments in a 12- by 12-foot bunker. The sand is collected below the bottom screen and moved by an inclined screw conveyor to an adjoining 10- by 10-foot bunker. This plant is wood construction on concrete foundations.

SODA ASH AND SALTCAKE IN CALIFORNIA

By Clarence R. King *

OUTLINE OF REPORT

INTRODUCTION

Sodium carbonate, Na_2CO_3 (the soda ash of commerce), and sodium sulfate, Na_2SO_4 (the saltcake of commerce), are among the most important of the alkalies. Of the heavy chemicals only sulfuric acid and common salt are produced in greater quantity than soda ash, and saltcake ranks sixth in point of production.

In the United States in 1939, the heavy chemical production in short tons was as follows:

Salt ($NaCl$)	10,003,448
Sulfuric acid (H_2SO_4)	7,711,487
Soda ash (Na_2CO_3)	2,960,722
Caustic soda ($NaOH$)	1,025,011
Chlorine (Cl_2)	490,256
Saltcake (Na_2SO_4)	337,243

The above approximate ratio of production holds to date; although production of each is about 50 percent greater at present.

Soda ash and saltcake enter the market either as the refined natural products recovered from saline lakes and bedded deposits in the western United States, or as manufactured chemicals made from common salt. Over 90 percent of the total soda ash and 80 percent of the saltcake production are manufactured from salt. At present, however, the production of natural soda ash and saltcake is expanding more rapidly than the production of the manufactured products.

POTENTIAL PACIFIC COAST SUPPLY AND DEMAND, 1950

It has been reliably estimated that present United States production of soda ash is 15 percent under present essential requirements. Total 1946 production was approximately 4,500,000 tons. Thus a deficit of some 800,000 tons per year is indicated. An estimate of proposed plant expansion and new plants in the United States which will increase the available soda-ash supply by the first part of 1950 indicates that some 22,000 tons monthly additional production may be expected from natural sources, and about 3,500 tons monthly from ammonia-soda plant expansion. This would total about 306,000 tons per year, leaving an indicated deficit of nearly 500,000 tons per year under present essential requirements, without taking into account possible increases in present demand or allowing for exports.

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Table 1. Comparative analyses of the brines of some California saline lakes

Lake	Content in grams per liter of calculated compounds								
	Soda Na_2CO_3	Saltcake Na_2SO_4	Salt NaCl	Borax $Na_2B_4O_7$	Potash KCl	Calcium bicarbonate $CaHCO_3$	Magnesium bicarbonate $MgHCO_3$	Miscellaneous and organic	Total salinity
SEARLES[1]	47.00	69.60	163.50	15.00	47.00	------	------	4.78	346.80
OWENS[2]	19.53	5.90	15.05	1.58	2.03	0.04	0.31	4.30	48.73
OWENS[3]	136.10	53.50	222.80	17.80	32.50	------	------	0.90	431.10
MONO[4]	23.47	8.97	18.51	0.20	1.83	0.08	0.33	0.07	53.47
MONO[5]	20.02	9.70	19.00	0.35	1.81	0.05	0.17	0.07	51.17
SODA[6]	19.29	110.32	250.99	3.10	0.10	------	------	------	383.71
BLACK[7]	12.30	3.64	1.80	Tr	0.71	------	------	0.06	18.50
BORAX[8]	28.99	0.11	38.99	5.00	2.20	0.06	0.09	0.32	76.56
SALINE VALLEY[9]	Tr	63.20	278.00	Tr	7.90	0.70	0.10	5.20	355.10
VALLEY SPRINGS[10]	29.45	11.11	31.40	Tr	2.27	------	Tr	1.26	75.49
DEATH VALLEY[11]	Tr	4.70	187.70	Tr	2.90	0.40	0.70	7.30	203.70
DALE[12]	Tr	70.00	220.00	Tr	0.10	------	------	8.00	298.00
DEEP SPRINGS[13]	20.80	12.90	81.10	0.89	24.10	------	------	3.00	142.79
BRISTOL AND CADIZ[14]	$CaCl_2$ 12.20	$MgCl_2$ 1.60	57.80	$CaSO_4$ 0.39	1.98	------	------	------	73.97

[1] Searles Lake, San Bernardino County, in Tps. 25, 26 S., R. 43 E., M. D. Analysis from Bradley, W. W., Flow sheet of the American Potash and Chemical Corp. (see references).

[2] Owens Lake, Inyo County, Tps. 16, 17, 18 S., Rs. 36, 37, 38 E., M. D. Analysis from Bailey, G. E., The saline deposits of California (see references). This represents the analysis in 1902, when Owens Lake was a large body of water.

[3] Owens Lake. Recent analysis of the saturated brines obtained from wells in the dry lake bed. Analysis from Dub, G. D., private communication.

[4] Mono Lake, Mono County, Tps. 1, 2, 3 N., Rs. 26, 27, 28 E., M. D. Analysis from Bailey, G. E., op. cit.; represents composition of the water in 1902.

[5] Mono Lake, analysis from Clarke, F. W., Data of geochemistry (see references). Represents the composition of the water in 1924.

[6] Soda Lake, San Bernardino County, Tps. 12, 13, N., Rs. 8, 9 E., S. B. The sink of the Mojave River, normally a dry lake. Analysis from Phelan, W. C., Salt resources of the United States (see references).

[7] Black Lake, Mono County, T. 1 S., R. 31 E., M. D., near Benton Station. Analysis from Clarke, F. W., op. cit.

[8] Borax Lake, Lake County, T. 13 N., R. 7 W., M. D. Analysis from Clarke, F. W., op. cit.

[9] Saline Valley, Inyo County, T. 14 S., Rs. 38, 39 E., M. D. Sample taken from surface hole in the crystalline salt beds; probably lower in sodium sulfate than deeper brines.

[10] Valley Springs, Death Valley, San Bernardino County, T. 19 N., R. 4 E., S. B., 7½ miles south of Confidence Mill. The Armagosa River surfaces at a bedrock rib at this point. Probably large flow of this type brine available.

[11] Samples from lower points in the Death Valley salt beds taken from pot-holes in the crystalline salt. Not representative of deeper brines, which are probably higher in sodium carbonate and sodium sulfate than analysis reported.

[12] Dale Lake, San Bernardino County, T. 1 N., R. 12 E., S. B. Worked by the Desert Chemical Company for both crustal thenardite and salt and saltcake extracted from brines.

[13] Deep Springs Lake, Inyo County, T. 8 S., R. 36 E., M. D. Analysis from Mineral Resources U. S. 1917, pl. 2, p. 417.

[14] Cadiz and Bristol Lakes, San Bernardino County, Tps. 2, 3, 4, 5 N., Rs. 12, 13, 15 E., S. B. Analysis from Mineral Resources of the United States, op. cit. Both of these dry lakes carry brines beneath the surface that are extremely unusual in that no carbonates and few sulfates are present. The high content of calcium chloride is not known in other California lakes and playas.

Appendix to Table 1

Other closed-basin California saline lakes

The following relatively minor closed-basin playa or permanent-water saline lakes might have possibilities as sources of soda ash or saltcake. None of them have been adequately prospected for salines.

HONEY LAKE

Lassen County, elevation 3949 feet, area approximately 64,000 acres, depth 0 to 2 feet, mean rate of evaporation 42 inches annually. Honey Lake is a closed sink, and present drainage into it is approximately 200,000 acre feet annually, as represented by the calculated mean annual evaporation from its surface. The waters are strongly alkaline and unfit for human use and always have a greenish-yellow color caused by impalpable mud held in suspension.

BLACK LAKE

San Luis Obispo County, in Bolsa de Chamisal Rancho, 1.5 miles east of the coast. Receives the drainage of Black Lake canyon. Arroyo Grande topographic sheet.

ALKALI LAKE

Mono County and Douglas County, Nevada (on the state line), no outlet, about 2 miles long, 1 mile maximum width, elevation "somewhat under 5,000 feet". Markleeville topographic sheet.

ALKALI LAKES

Modoc County, Surprise Valley; no outlets; three lakes, lower two connected. They are typical playa lakes, becoming completely desiccated during the dry season, leaving fields of salt or cream-colored mud. Elevation 4700 feet. Alturas topographic sheet.

ANNIE LAKE

Modoc County, northeast part, 3 miles southeast of Bidwell Peak, no outlet. Altitude about 5000 feet. Alturas topographic sheet.

CLARK LAKE

San Diego County, Tps. 9, 10 S., Rs. 6 and 7 E., S. B. An intermittent body of water occupying a depression 542 feet above sea level. Indio special topographic sheet.

ELSINORE LAKE

Riverside County, Tps. 5 and 6 S., Rs. 4 and 5 W., S. B. A body of brackish water approximately 5 miles long by 2 miles wide. Elevation 1220 feet. Elsinore topographic sheet.

This indicated shortage may be accentuated on the Pacific Coast in view of the rapid growth of heavy industry and increase in population. During the first part of 1947, soda-ash production in California (all from natural sources) was about 23,000 tons monthly, of which approximately 3,000 tons monthly was consumed in other states, leaving about 20,000 tons monthly or 240,000 tons yearly to satisfy California demand. A fair guess as to the potential market for soda ash in 1950, on the Pacific Coast, would be about 400,000 tons per year. Probable western production by 1950, based on present proposed or under-construction expansion, will be about 350,000 tons per year, leaving an estimated deficit of some 50,000 tons per year to be met by further increase in productive capacity from natural California and western sources; construction of one or more ammonia-soda plants on the Pacific Coast; or a levelling off or slump in the steady growth of heavy industry on the west coast.

Exploitation of natural deposits not at present productive would involve relatively heavy capital expenditure in preliminary work and plant construction and would take several years. Of the deposits known, Mono Lake, Death Valley (Valley Springs), Deep Springs and Soda Lake (see table 1) have the largest reserves of soda ash and saltcake. Mono

Table 2. Approximate comparative physiographic data on some California saline lakes and playas

Place*	Elevation, feet	Area, acres	Average depth, feet	Annual rainfall, inches	Annual rate of evaporation, in.	Average temp. Apr.-Sept. incl.	Average temp. Oct.-Mar. incl.
Mono[4]	6380	53000	62	18	95	65	35
Owens[2]	3569	64000	0–10	3.06	100	80	45
Searles[1]	1623	10000	top dry	4.5	110	79	53
Black[7]	6422	200	----------	5	95	80	45
Borax[8]	1333	320	0–10	23	35	67	49
Valley Springs[10]	50	----------	top dry	1.7	110	91	61
Death Valley[11]	—250	65000	top dry	1.7	110	91	61
Saline Valley[9]	1500	12000	0–2	3	100	80	45
Deep Springs[13]	4950	600	2–10	5	85	75	40
Soda[6]	910	34000	0–1	3	110	80	55
Bristol-Cadiz[14]	600	25000	top dry	2	100	85	60
Dale[12]	----------	2000	top dry	5	100	79	55

* Footnotes are under table 1.

Table 3. Estimated salts content, in millions of tons, of some California saline lakes and playas

Place*	Na_2CO_3	Na_2SO_4	$Na_2B_4O_7$	NaCl	KCl
Mono[4]	92.1	47.6	0.9	86	10.5
Owens[2]	22	22	0.9	20	2.1
Searles[1]	158	----------	17	200	30
Black[7]	0.10	0.03	----------	0.06	0.01
Borax[8]	1.5	----------	0.3	2.5	0.1
Valley Springs[10]	----------	----------	----------	----------	----------
Death Valley[11]	1	100	4	300	13
Saline Valley[9]	0.1	35	0.1	157	4
Deep Springs[13]	1.4	0.9	0.5	5.7	1.5
Soda[6]	5	50	4	100	0.5
Bristol-Cadiz[14]	----------	----------	----------	----------	----------
Dale[12]	----------	20	----------	60	----------

* Footnotes are under table 1.

Lake appears to be the best potential producer, if the disadvantages of inaccessibility, comparatively short solar evaporation season, and relatively dilute brine, can be overcome. Accurate data on the constitution and amounts of brines available in Death Valley, Deep Springs, and Soda Lake are not available, and much drilling and testing would have to be done before a process could be worked out and plant construction started. Many smaller potential sources of soda ash and saltcake are listed in the reports cited in the bibliography attached to this paper.

Further increase in productive capacity of present plants operating on the saline lakes of California cannot be expected to augment present production by more than about 25,000 tons monthly of soda ash without exceeding the economic rate of withdrawal of brines, according to available data.

Discovery of new large sources of soda ash and saltcake in California is unlikely. A factor that might influence price and supply of soda ash on the Pacific Coast is the recent discovery of very large deposits of trona 20 miles west of Green River, Wyoming, at depths ranging from 1500 to 1600 feet. The beds of comparatively pure trona (sodium sesquicarbonate) are 10 to 20 feet thick and are adapted to cheap room and pillar mining. Probable reserves are estimated to be hundreds of millions of tons of trona. Late in 1946 preliminary drilling was completed and a

working shaft started. Production is expected by the middle part of 1948 or sooner.

Installation of Solvay or electrolytic plants in the immediate future is unlikely in California except possibly in cases of captive plants producing soda ash or caustic soda for use in manufacturing processes by the firm owning the plant. Comparative economics of the two processes in these cases will probably result in the installation of electrolytic process plants rather than Solvay plants on the Pacific Coast. Electrolytic caustic soda must be considered in any evaluation of the soda-ash market, even though the production of caustic soda is largely influenced by the demand for chlorine. Depending on overall economic factors, caustic soda may be converted to soda ash or substituted for soda ash in many uses; or soda ash may be causticized or substituted for caustic soda in some uses.

COMMERCIAL CARBONATES OF SODA

The sodium carbonates are listed below in the order of their commercial importance.

Soda ash (normal sodium carbonate, Na_2CO_3) is marketed in various degrees of purity based on the sodium oxide (Na_2O) content and on its physical characteristics. Most soda ash is sold on a basis of 58 percent Na_2O (99 percent Na_2CO_3) content, and classified as to physical characteristics as follows:

(1) Extra-light ash (density 23 pounds per cubic foot)
(2) Light ash (density 32 to 35 pounds per cubic foot)
(3) Medium-dense ash (density 50 pounds per cubic foot)
(4) Heavy dense ash (density 65 pounds per cubic foot)
(5) Fused blocks (each block weighing 4 pounds)

Monosodium carbonate ($NaHCO_3$), the common bicarbonate of soda, is marketed according to the purity of the salt with special reference to toxic impurities, since the chief uses are in baking soda, baking powders, etc., for human consumption.

Sodium carbonate decahydrate ($Na_2CO_3.10\ H_2O$) is made by cooling a properly concentrated solution of soda ash to a temperature below 32° centigrade. Its chief use is as a cleansing agent.

Sodium sesquicarbonate ($Na_2CO_3.NaHCO_3.2H_2O$) is the commonest form occurring in nature. This sodium carbonate is the mineral trona. Most soda ash from natural sources is made from trona by calcination. The chief uses are in the laundry industry, the textile and tanning industries, and in general cleaning.

Sodium carbonate monohydrate ($Na_2CO_3.H_2O$) is formed when a strong solution of soda ash is cooled to 35° centigrade or by crystallization from a saturated boiling solution of soda ash. Its chief uses are in the chemical industry, in cleaning and boiler compounds, and in photography.

SODA ASH

Uses and Marketing

Soda ash has from the earliest times been used chiefly in the glass, ceramic, soap, and cleanser industries. The distribution of consumption by industries in the United States in 1939 is a fair cross-section of world use of soda ash:

	Percent
Glass, soap and cleanser industries	36.5
Manufacture of caustic soda and other sodium chemicals	49.0
Pulp and paper, aluminum, textile, and petroleum industries	11.6
Miscellaneous industries	2.9
Total consumption	100.0

Because of the present acute shortage, the following standard quotations (from the Oil, Paint and Drug Reporter for January 6, 1947) are nominal. Lots of soda ash, f.o.b. New York or Pacific Coast points, have sold recently from $65 to more than $150 per ton, and an active distress demand exists at these extreme prices.

Standard quotations—soda ash

100-pound bags, dense, 58 percent, l.c.l. zone 1	$2.63
zone 2	2.78
zone 3	3.13
zone 4	3.73
Dense, 58 percent, in bulk, c.l. plants per cwt.	1.08
Light, 58 percent, in bags, c.l. plants per cwt.	1.20
Light, 58 percent, in bulk, c.l. plants per cwt.	1.00
Extra light, 58 percent, l.c.l., in bags, $2.65 to $3.75, according to zone	

Sales zones on soda ash are as follows:

Zone 1—All states east of Mississippi River and north of south boundary of Kentucky and Virginia; also Alabama, Louisiana, and Mississippi south of 31° latitude; Florida, also Maine, New Hampshire, and Vermont; Davenport, Iowa, and St. Louis, Missouri.

Zone 2—Arkansas east of 98° longitude, Georgia, Iowa (except Davenport), Minnesota, Missouri (except St. Louis), Nevada east of 98° longitude, North Carolina, South Carolina, Tennessee, and Texas north of 31° latitude.

Zone 3—Arkansas west of 96° longitude, Kansas, Nebraska west of 98°, North Dakota, Oklahoma, South Dakota, Texas west of 100° (including Wichita Falls, excluding El Paso).

Zone 4—Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming, and El Paso, Texas.

California, Washington and Oregon are a separate sales entity, but nominal prices are in line with Zone 4 on imports and car-lot plant prices on local production.

Sodium bicarbonate—U.S.P. grade, c.l. plants, bags	$2.25 cwt.
Caustic (sodium hydrate)—flake, powdered, 76 percent drums, c.l. plants	3.00 cwt.
Sesquicarbonate (trona)—bags, c.l. plants	1.70 cwt.

Manufacture

Soda ash has been made from common salt by three processes.

LeBlanc Process. The LeBlanc process produces soda ash from saltcake. The saltcake usually originates from plants manufacturing hydrochloric acid by the reaction of salt with sulfuric acid to form saltcake and hydrochloric acid. The saltcake is roasted with ground limestone and a reducing agent such as powdered coal. Sodium sulfide is formed and this reacts with the limestone to form sodium carbonate and calcium sulfide. This process is obsolete, and no plants using it have been built in the United States.

Electrolytic Process. The electrolysis of salt solution resulting in the evolution of chlorine and formation of caustic soda in solution is at present a rapidly growing industry. The economics of this process depend upon cheap electrical energy and a market for the chlorine and

hydrogen, as well as the sodium chemicals produced. Essentially the process involves the electrolytic decomposition of brine in a properly built cell. The quantitative relationship of the materials used and produced by this process is shown below.

For each ton of 76 percent NaOH, 1,750 pounds of Cl_2 and 50 pounds (8,750 cubic feet) of H_2 produced, the following are used:

Common salt	1.6 tons
Sodium carbonate	50 pounds (58 percent soda ash)
Sulfuric acid	200 pounds (66°Be)
Steam (low pressure)	20,000 pounds
Electrical energy	2,500 kilowatt hours
Refrigeration	0.9 ton
Direct labor	18 man hours

Ammonia-Soda (Solvay) Process. More than 90 percent of all soda ash is made from common salt by the Solvay process. The process involves the reaction of a strong purified brine with ammonium bicarbonate resulting in the formation of sodium bicarbonate and ammonium chloride.

The sodium bicarbonate precipitate is separated from solution and converted to soda ash by calcination; and the ammonia is recovered by the action of the ammonium chloride solution on lime, which results in the formation of ammonia gas and calcium chloride solution. The economics of the process depend upon the juxtaposition of abundant and cheap limestone; cheap fuel (natural gas, oil, or coal); abundant water; and abundant cheap supply of salt or strong salt brine: all reasonably close to a market for soda ash. Capital investment for a Solvay-process plant was approximately $12,000 per 24-hour ton capacity in 1939, but in 1946 was about double that figure. Eighteen Solvay plants were operating in the United States in 1942.

The quantitative relationship of materials and products in this process is shown below.

For each ton of 58 percent soda ash produced the following are used:

Common salt	1.5 to 1.75 tons
Limestone	1.2 to 1.35 tons
Coke	0.095 to 0.11 ton
Coal (boiler firing)	0.25 to 0.50 ton
Coal (drier firing)	0.16 to 0.25 ton
NH_3 (makeup of losses)	4 to 9 pounds
CO_2 (from limekilns)	1,000 to 1,200 cubic feet
Cooling water	15,000 to 18,000 gallons
Direct labor	2 man hours
Maintenance	2.6 man hours

To date no ammonia-soda plants have been built on the Pacific Coast.

Recovery from Natural Solid or Brine Deposits

Soda ash (Na_2CO_3) is never found free and in the solid state in nature because of its extreme solubility in water (7.1 percent by weight), and the tendency to form the sesquicarbonate and other less soluble carbonates, and the sulfate.

Most alkali lakes and playas in the west contain sodium carbonates and sulfate in solution along with common salt and other saline compounds. These were derived from the rocks within past or present drainage areas of the lakes, and were concentrated in their closed basins by evaporation. Many of these lakes mark the deepest parts of the great Quaternary fresh-water lakes of the Great Basin region. Lake Bonne-

ville on the eastern border of the Great Basin is represented by the Great Salt Lake of Utah, which occupies the deepest part of that ancient lake basin. The present saline lakes of Winnemucca, Humboldt, Carson, and Walker, occupy the lowest depressions in the bed of the ancient Lake Lahontan. Death Valley, Searles Lake, and Owens Lake occupy the lowest pools of the Quaternary Lake Aubury; and the Salton Sea and Dale Lake occupy low parts of the bed of old Lake LeConte. These tremendous Quaternary lakes literally dried up after the close of the Quaternary glacial epoch, and the dissolved salts contained in their comparatively fresh waters were concentrated manyfold in the residual pools occupying the deepest depressions in the ancient lake beds.

In California the alkaline deposits of Searles Lake, Owens Lake, and Mono Lake are best known. The deposits in Owens and Searles Lakes have been exploited commercially for many years. Those of Mono Lake have not to date been successfully exploited because of the relative inaccessibility of the lake and the comparatively short and cold solar-evaporation season. Reference to the accompanying tables of approximate comparative data on the principal saline lakes and playas which might produce or are producing soda ash or saltcake will show the large reserves of the sodium chemicals available in the alkali lakes of California.

The recovery of soda ash and other salines from alkaline lake brines depends upon the type of brine and concentration. In the case of Owens Lake brines, the present process involves six or more steps: (1) Evaporation of the lake waters (raw brine) in solar ponds to a specific gravity of about 1.36 (approximately 360 grams per liter total salinity), and a Na_2CO_3-content of approximately 100 grams per liter or more; or control of the brine wells on the lake surface so as to produce saturated brine directly from that part of the lake bed now dry at the surface; (2) Heating and carbonation of the concentrated brine; usually done by steam heating and carbonation in tall towers through which boiler flue gas high in CO_2 is blown; (3) Step "2" precipitates sodium bicarbonate and sesquicarbonate, and the carbonated brine containing precipitated crystals is settled in thickeners, to allow decantation of clear mother liquor, and also to allow time for the relatively complete precipitation of bi- and sesqui-carbonate; (4) The thickener underflow (settled sludge) is centrifuged or filtered and the comparatively dry crystalline bi- and sesqui-carbonate recovered; (5) The mixed carbonates are calcined to soda ash; (6) The mother liquor remaining after centrifuging and settling out the precipitated trona (sesqui-carbonate) is either run to waste or treated for the recovery of borax and potassium chloride.

In the case of the brines pumped from Searles Lake, the recovery process is much more complicated, because of the relatively high content of potash, borax, lithium, and other valuable salts along with the soda ash. The Searles Lake brine as pumped from wells on the dry "lake" is saturated with five or more salts, the total salinity being over 300 grams per liter. It is pumped directly into the refining plant without solar evaporation. The recovery process involves carefully controlled heating, carbonation, and fractional crystallization; first removing most of the salt, sodium sulfate, and sodium carbonate; then crystallizing out the potassium chloride, then the borax. Each of the fractions is further purified, by-products being lithium salts and bromine; primary products are soda ash, saltcake, refined borax, and sulfate and chloride of potash.

Capital investment in plants for the recovery of soda ash, saltcake, and other salines from natural deposits in California, ranges from a few hundred dollars per ton daily capacity in the case of small ''haywire'' plants (in which beds or solid crusts of saltcake or trona are mined or scraped up and sold as crude salts, or refined by simple solution and recrystallization in vats), to over $20,000 per daily ton capacity in the case of modern plants such as are now operating on Searles and Owens Lakes. No precise figures on capital investment can be presented without detailed data upon the particular deposit under scrutiny, including the amount and nature of all the salines present which might be profitably recovered, the recovery process applicable to the deposit, the proposed scale of operation, and the location and climate.

COMMERCIAL SODIUM SULFATE (SALTCAKE)

Manufacture from Salt

Over 80 percent of the 1939 United States production of saltcake (337,243 tons) was a by-product from the manufacture of hydrochloric acid from salt and sulfuric acid. The quantitative relationship between products and materials used in this process is shown below.

To produce one ton of 20° Baume hydrochloric acid and 1,260 pounds of saltcake, the following are used:

Salt	1,050	pounds
Sulfuric acid (100 percent acid)	945	pounds
Coal	740	pounds
Water	2,900	gallons
Electrical energy	90	kilowatt hours
Direct labor	5.3	man hours

Approximately 25 plants in the United States produce saltcake by this process. Most of the western demand is supplied by saltcake recovered from natural deposits such as surface saline crusts or brines of alkaline lakes or playas, or from bedded deposits of sedimentary origin, in California.

Uses and Marketing

Sodium sulfate (saltcake) is used in making wood pulp by the sulfate process, in the glass industry, and in the chemical industry. Minor uses are in the tanning and dyeing industries, in medicines, and in fertilizers. In recent years saltcake has been substituted for soda ash in many industries to a greater or less degree; and the present market is absorbing the available supply, with prospects of a temporary shortage until productive capacity is increased.

Commercial sodium sulfate is sold in three forms: saltcake, Glauber's salt, and niter cake. Saltcake, anhydrous sodium sulfate (Na_2SO_4), may be either the residue from the manufacture of hydrochloric acid or the natural anhydrous sodium sulfate (thenardite). Glauber's salt, hydrated sodium sulfate ($Na_2SO_4.10H_2O$), may be manufactured from anhydrous sodium sulfate or recovered as the natural mineral mirabilite. Niter cake is the residue from the manufacture of nitric acid from sodium nitrate (Chile saltpeter) and sulfuric acid, and is an anhydrous sodium sulfate comparable to saltcake. Except for isolated cases, no distinction is made in the United States markets between niter cake and saltcake.

Saltcake is sold on a minimum Na_2SO_4 basis, usually 98 percent plus; in some cases a maximum limit of 1 to 3 percent is placed on magnesia, and sometimes there is a maximum limit on lime content.

June 1947 standard market quotations on mid-west and eastern saltcake are $20-$28 per short ton, bulk, at producing plants. California prices are within the same range; but long-term contracts and distress buying have caused variations above and below this range.

Recovery from Natural Deposits

The recovery of saltcake from natural deposits in California has so far been confined to: (1) Mining, by underground or open-cut methods, of bedded deposits in Quaternary or Tertiary sediments deposited in ancient lakes; (2) Recovery from dry or playa alkaline lakes where saltcake forms as a shallow saline crust comparatively low in salt content, and where it can be scraped into piles for loading and refining; (3) Recovery from alkaline lake brines as a by-product in the recovery of soda ash, potash, or borax; or, in the case of brines which are high in saltcake and low in other alkalies, by solar evaporation in ponds. If this evaporation is done in the winter when average temperatures are below 45° fahrenheit, saltcake will crystallize out of the brine when the specific gravity approaches 1.3, leaving most of the salt in solution.

Large reserves of natural sodium sulfate exist in California, and some additional production may be quickly attained with comparatively low plant investment at several deposits now idle, as well as at others now producing. Most of the present California production is a by-product from the recovery of soda ash, borax, and potash from Searles Lake brines. Increase in production of soda ash would increase the production of saltcake from these brines. If future market conditions lead to the construction of new plants for the production of saltcake in California, the most promising deposits appear to be:

(1) Soda Lake, the sink of the Mojave River.
(2) Dale Lake, San Bernardino County.
(3) Mono Lake, Mono County.
(4) Carrizo Plains (Soda Lake), San Luis Obispo County.
(5) Imperial Valley, near Bertram Station on the Southern Pacific Railway in Imperial County.
(6) Buckhorn Springs, south of Muroc, Kern County (secs. 27 and 28, T. 9 N. R. 10 W., S. B.).
(7) Emerson Lake, San Bernardino County.

Of these, the first two are playas (dry lakes); these might furnish high-sulfate brines as well as solid saltcake crusts or bedded thenardite. Both are accessible to railroad transportation. Recovery of saltcake from Mono Lake would be dependent upon the recovery of the soda ash and other valuable saline constituents. Comparatively low concentration of salines in the water, inaccessibility, and short solar-evaporation season are obstacles to commercial exploitation of the waters of Mono Lake. The deposit of sodium sulfate at Carrizo Plains is in the form of a thin (1- to 6-inch) crust with possibly thicker "channels" covering a large area, which is renewed after removal, by solar action on the sulfate-bearing muds of the lake beds. This deposit has been worked in the past, producing comparatively pure saltcake. The nearest shipping point is McKittrick, 18 miles by road. The Imperial Valley deposits are beds of varying purity and thickness, which may be mined by open-cut methods over an extensive area. The Buckhorn Springs deposit in Kern County is undeveloped. It is apparently a series of thin beds. The deposits near Emerson Lake, San Bernardino County, are undeveloped, and appear to be thin crusts as well as some workable bedded deposits.

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THE LAKES OF CALIFORNIA

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OUTLINE OF REPORT

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This paper is reprinted from the *California Journal of Mines and Geology* for January-April 1933, vol. 29, nos. 1-2, pp. 175-236.

THE ORIGIN OF LAKES

The Forms of the Lands

The forms of the lands are determined in the main by the slow interaction of two antagonistic processes. One process, of interior origin and unsolved explanation, slowly deforms the earth's crust and makes its surface uneven. Associated with this deforming process in being of interior origin and of difficult explanation, but apparently acting independently of it, are volcanic eruptions which build up cones and domes and pour out lava flows of smaller or larger extent.

The other process, of exterior origin and simpler explanation, includes all the agencies which tend either to wear down the land surface and reduce the uneven highlands to smooth lowlands or to fill up depressed basins and convert them into smooth plains. Chief among these agencies are weathering and streaming; that is, the ordinary agencies by which rocks are disintegrated, by which valleys are deepened and widened, and by which the irregular slopes of the deformed crust are graded down or graded up to regular slopes and eventually smoothed out as plains. Associated with these familiar agencies are certain more special agencies, such as the glaciers of high mountains and the ice sheets of the Arctic and Antarctic regions; also wind action in deserts, solvent action in limestones, and wave and current action on sea and lake shores.

The fact that many unevennesses, such as mountains and highlands, exist today does not mean that the earth's history is so short that its primitive unevennesses have not yet been worn down, for all unevennesses of ancient origin were worn down ages ago. Existing mountains and highlands are of later upheaval; and although they are vastly more ancient than human history, they are young as the earth measures time; so young that they have not yet been worn down, although the agencies of weathering and streaming have very generally made good progress in carving valleys of continuous descent down their slopes. Hence it may be said in a general way that the highest mountains of today are high because they are geologically young; they represent, although already much dissected by deep-cut valleys, the latest great upheavals that the earth's crust has suffered. It should be understood, however, that geologically young mountains are historically so ancient that they antedate all human records.

The Antagonism of Lakes and Rivers

Inasmuch as rivers carve valleys of continuous down grade from head to mouth, they tend to destroy lakes; for the floor of every lake basin must have an up-grade from its deepest part to the lake outlet. The occurrence of lakes therefore suggests an imperfection or an incompleteness in the down-grading action of rivers, and hence a study of lakes must involve a search for the origin of such imperfection or incompleteness. Such study shows that basin-like depressions, large or small, have been produced in the surface of the lands by irregular deformation of the earth's crust. If the deformation is slow, the resulting basin may be filled with inwashed detritus while the deformation is in progress, and no lake will be formed; but if the deformation is more rapid, the basin will be only in part filled with detritus during its deformation, and a lake will occupy the unfilled part. Where the climate is moist such basins are water-filled to overflowing; where it is dry the basin is only in part water-filled and there is no overflow. In this case the area of the non-overflowing lake comes to be such that evapora-

tion from its surface disposes of the inflow from the entire drainage basin: in the other case the overflow will equal the inflow minus the evaporation from the lake surface.

The study of lakes also shows that some of them occur where the land surface has been unevenly worn down by ancient glaciers, or where it has been unevenly up-built by volcanic eruptions. Moreover, certain desert regions, in the broad basins of which lakes are now small or wanting, are shown by the shore-line terraces still preserved on the basin slopes to have possessed large lakes during a moister and cooler climatic period of the geologically recent past, presumably contemporaneous with the period in which the ancient mountain glaciers and the great ice-sheets of certain continental areas attained their vast extension. All these possible causes of lake production must be investigated.

The study of lakes shows further that, whenever and wherever they are produced, the action of weathering and streaming tends, as above intimated, to destroy them, either by slowly filling their basins with inwashed detritus or by gradually cutting down their outlets and draining off their waters. Thus Lake Geneva, at the northwestern margin of the Swiss Alps, is now somewhat encroached upon by the delta that the inflowing Rhone is building at the lake head; eventually, the delta may replace the entire lake. Likewise, Lake Erie is fated to be drained away in the distant future when Niagara Falls and the rapids upstream from them are worn back sufficiently to lower the lake outlet to the level of its basin floor, which will then be laid bare as a smooth plain.

Lake basins should therefore be considered as resembling, in a smaller way, the greater uneveness of the earth's surface, because they also very generally exhibit the interaction of antagonistic processes: one set of processes producing the lake-holding basin, the other set tending to destroy the lake-holding basin. In other words, the quicker-acting but less enduring processes of lake production are, in time, overcome by the slower acting but longer enduring processes of lake destruction. Lakes are therefore, as a rule, what our old Mother Earth would consider short-lived features of her land surfaces. A few examples of these general principles may be here presented.

Divers Methods of Lake Production

Warped-Valley Lakes

A slight bending or breaking of the earth's crust will affect the slope of river basins and their valleys. If a valley slope is thus increased, its river will run faster and erode its valley deeper; but if a valley slope is decreased even to the point of reversing its direction, a lake may be formed in the depressed part of the valley. A peculiar lake in equatorial Africa illustrates this method of lake-production to perfection. The headwater area of a region drained by the Kafu and Katonga rivers has been slightly down-warped, so that their valleys now slope eastward instead of westward as formerly. The branching Kafu headwaters have thus been transformed (pl. 24*A*) into the branching Lake Kyoga, 150 miles in length. The Katonga headwaters are more completely submerged in the broad Lake Victoria, of similar measure in diameter. Parts of both rivers now flow backwards into their lakes. Lake Victoria is the chief source of the Nile, which flows northward from it into Kyoga Lake by one of its branches and out by another. The little eroded Ripon Falls, next north of Lake Victoria, and the extremely narrow gorge below

Murchison Falls, northwest of Lake Kyoga, testify to the recency of the time when the lakes were formed and the present course of the Nile was assumed.

Fault-Basin Lakes

Certain lakes occupy depressions in the land surface which result from the breaking and tilting of huge blocks of previously nearly level earth-crust (pl. 24*B*). The deep fractures on which such blocks are displaced are known to geologists as faults, and the displaced blocks are called fault-blocks. When some of the blocks are raised to mountainous heights (pl. 24*B*) the depression between them may be called an intermont trough or basin. Some such basins are of so recent a geological date of formation that they have not as yet been much filled by detritus washed down from the adjoining highlands, and rather deep lakes may then occupy a considerable part of their cavities. Central Africa again affords a typical example of this kind in the long and deep Lake Tanganyika; and the exceptionally long and deep Lake Baikal of north-central Asia may be of similar origin.

Other fault basins of more ancient origin are now largely filled with evenly spread layers of inwashed detritus, coarser and steeper-sloping near the base of the enclosing highlands, finer and more nearly level near the basin center. The basins are thus converted into flat, intermont plains, while the uplifted blocks are carved into rugged mountainous forms. Such basins are said to be aggraded, while the mountain blocks are dissected or degraded. Shallow lakes may then occupy the least filled parts of the plains (foreground, pl. 24*B*).

It must not be imagined that the faulting or flexing of such crustal blocks took place suddenly or that the resulting troughs or basins immediately became filled with great bodies of water. The displacements were probably accomplished by many small movements separated by quiet pauses of years or centuries; and it is to be supposed that a considerable quantity of detritus was washed into the cavities from the enclosing highlands while the displacements were in slow progress. The displacements may have been, in some cases, so slow that the larger rivers of the deformed region held their courses, by cutting deep gorges through the uplifted blocks and filling the depressed areas with detritus. In all cases any lakes that were thus formed occupy merely such parts of the basins as are not otherwise filled. All such lakes may therefore be roughly classified with respect to the proportion that their water volume and area bear to the volume and area of the basin of deformation.

Intermont lakes will overflow if the climate is humid, but not if the climate is arid; for in the latter case evaporation from the lake surface disposes of all the water that the lake receives from rainfall and from inflowing streams and springs. Lakes without outlets are commonly saline, because as told above the minute amount of dissolved saline minerals brought in by their streams accumulates in them. If these lakes lie on the plains of smoothly aggraded intermont depressions, they may be so shallow even during the wetter part of the year that they evaporate in the drier part, leaving a smooth plain of silt in their place. Plains of this kind are called playas and the thin water sheets that temporarily cover them are known as playa lakes.

Nevada, Arizona, and southern California, of arid climate, possess a good number of intermont depressions of earlier or later origin, the depth

of which has been more or less diminished by deposits of inwashed detritus. Hence, besides some good-sized and rather deep lakes in the younger and less filled depressions of western Nevada, the flat, aggraded floors of many other depressions of the two states contain only dry lake beds or playas, mostly of moderate or small area. These are flooded, if at all, only after winter rains or summer downpours, and even then only by very shallow water sheets. But many of these heavily aggraded basins held much larger perennial lakes during the cooler and moister glacial period of modern geological times.

Landslide Lakes

It sometimes happens that a steep-sided, stream-eroded canyon is blocked by a landslide, upstream from which a lake then rises (pl. 26*A*). A famous example of this kind occurred in a deep and steep-sided valley of the Ganges headwaters in the Himalaya Mountains of India in September 1893. The slide descended some 4000 feet, leaving a great bare scar at its source, and forming a barrier in the valley two miles long and from 800 to 900 feet high. A lake gradually rose behind it and gained a length of over three miles. Then overflowing some eight months later, the outrushing flood rapidly cut a gash a mile long and nearly 400 feet deep through the barrier. The lake fell 25 feet in the first hour after its overflow began and 300 feet in the second hour. The resulting flood rose 160 feet 20 miles down the valley and from 50 to 60 feet 70 miles down. Yet such were the precautions taken and so well was the coming of the flood announced by telegraph to the villages down the valley that, although all houses and bridges were swept away, livestock was driven up the valley sides to safety and only one human life was lost, that of a religious devotee who insisted on living at the base of the slide. He was never found after the overflow took place.[1]

If the obstruction produced by a landslide does not block a valley to a great depth, the outlet of the resulting lake will, on overflowing, cut down its course gradually and the lake will be slowly lowered. A great, prehistoric landslide, descending a slanting course of several miles on the Washington side, blocked the Columbia River about midway in its gorge through the Cascade Mountains and pushed the river toward the Oregon side; there the great river now has a cascading course among giant boulders and is striving to reestablish an even current and drain away its lake-like expansion that still remains next upstream from the obstruction; but as it has not yet succeeded in doing so, the slide must be of recent geological date. The name of the mountains through which the river has cut its deep gorge has been taken from the cascades of the river among the huge boulders of the slide.

Glacial Lakes

The great glaciers, which were formed on certain mountain ranges during the geologically recent, cooler and moister glacial period above referred to, scoured the bed rock of the highland valleys along which they crept, slowly and heavily, from higher to lower ground, and where the scouring was uneven, rock basins were excavated. Since the glaciers dis-

[1] Holland, T. H., The landslip at Gohna, Garwhal: Rec. Geol. Survey, India, vol. 27, pp. 55-64, 1894.
Strachey, The landslip at Gohna: Geog. Jour., vol. 4, pp. 162-170, 1894.
Lubbock, F., The Gohna lake: Geog. Jour., vol. 4, p. 457, 1894.

appeared in the warmer and drier climate of the present, the basins that they excavated are occupied by lakes. Many California lakes are of this kind.

The modification of mountain forms produced by glacial erosion and the intimate association of lake basins with that extraordinary process may be made clearer by reference to plate 25. On the extreme left is shown the preglacial form of a mountain range as produced by the prolonged action of ordinary weathering and streaming on an uplifted highland; not that all mountains had such forms in preglacial time but that many of them had. The timber line was then at a high level, appropriate to the mild preglacial climate. The dome-like summits gave forth rounded, branching ridges and spurs, which separated correspondingly branching valleys; and down the continuously descending floors of the valleys, slender and nimble water streams ran in winding channels on the narrow valley floors.

In the left center, where the timber-line is lower by reason of a colder climate, a glacial system, consisting of several short branches heading in broad reservoirs and uniting in a long trunk, has taken possession of the upper part of a valley stream and has reshaped the valleys to the satisfaction of the heavy and sluggish ice-streams. Each branch glacier has a concave surface in its gathering reservoir, but the trunk glacier assumes a convex surface as it sluggishly creeps down its course. Large as it is, all of its slow-moving volume is drained away by the slender ice-water stream that issues from a terminal ice cave. The several head glaciers have excavated great quarry-like cavities, known as cirques, in the valley heads, thus reducing the rounded mounts and ridges that enclose them to sharpened peaks and serrated crests; but unconsumed remnants of preglacial dome-tops survive here and there. Each branch glacier preserves its individuality in the trunk; for ice streams do not mix their currents as water streams do. Hence the detritus dragged along from the narrowed spurs between the head reservoirs is seen in long "medial moraines" on the surface of the trunk glacier. That great glacier has transformed a narrow-floored, preglacial valley into a strongly deepened and broadly opened but still steep-sided trough. The large size of the trough or ice-channel below the higher valley-side slopes is appropriate to the sluggish movement of the glacier, just as the small size of a valley-bottom stream channel is appropriate to the nimble flow of the water-stream.

A small share of the detritus removed by the plucking and scouring action of the heavy, slow-creeping ice from the walls and floors of the cirques and troughs, as well as of that washed down upon the ice from the higher, ice-free surfaces, is deposited in a terminal moraine which loops around the end of the glacier in ridge-like form; but most of the removed detritus is carried away by the ice-water stream. The occurrence of a larger exterior terminal moraine indicates the presence at an earlier time of a larger glacier by which part of the cirque and trough excavation must have been done.

While these changes are going on, the parts of the range not occupied by glaciers are worn down lower by ordinary weathering and streaming without significantly changing their shape, to some such measure as is shown by the vertical face between the extreme left and the left center of the diagram.

The right half of the diagram exhibits the mountains as they appear after the glaciers have melted away in the milder climate of postglacial

time. The timber line is at a higher level again. The rock floors of the cirques are often scoured out in shallow basins, holding lakelets or tarns. Talus from the steep rock walls encroaches more or less upon the floors of the cirques and troughs. It is noticeable that the short side troughs which head in lateral cirques "hang" above the much deeper floor of each great main trough. Streams, cascading down into the main trough, cut clefts and chasms in the lips of the hanging troughs, or hanging valleys as they may now be called, and build detrital fans below. The fans push the main trough stream toward the opposite side of the trough.

Small lakes may occupy shallow basins in the trough floor down stream from the cirques for a time after the disappearance of the glaciers; but many of them have been filled by stream-washed detritus which has built up or aggraded parts of the over-deepened floor in smooth flood plains or "meadows." The largest lake of the glacial system occupies the terminal part of the over-deepened floor, where the terminal moraine may aid in holding back its waters. The head of such a lake is partly filled in by the delta extension of the trough-floor flood plain.

Inasmuch as no great amount of talus has yet accumulated in the cirques, as the clefts cut in the lips of the hanging side valleys have not yet gained great depth, and as the terminal lake has not yet been completely filled by its growing delta, it must be inferred that the time since the disappearance of the latest glacial system is short compared to the time during which the valleys were occupied by that system as shown in the left-center of the figure, and shorter still compared to the time during which the mountain valleys, shown at the left end of the figure, were carved by ordinary weathering and streaming to the form they had before their occupation by ice.

The importance of glaciation in the production of lakes may be judged by the number and the size of such lakes in various parts of the world. For example, Okanagon, Arrow, Slocan and Kootenay in British Columbia, 60, 95, 23, and 68 miles in length, and the 65-mile Lake Chelan in Washington, all in valleys of the Columbia River system, occupy basins of glacial excavation. The same is true of the piedmont lakes of the Alps, including Annecy, Geneva, Thun-Brienz, Lucerne, Zurich, Constance, Ammer, Würm, and Chiem on the north, and Maggiore, Lugano, Como, Iseo and Garda on the south. Some of these lakes are over 1000 feet deep. They are all surrounded by beautiful mountain scenery, but the European examples have the additional and very picturesque attraction of long-established human occupation, while the American examples are for the most part in mountain wildernesses, scantily inhabited.

The great North American lakes, from those of the St. Lawrence system northwestward 2000 miles toward the Arctic Ocean, are all associated with the scouring action of the vast ice-sheets which covered northeastern North America in the glacial period, although it should not be asserted that they are wholly due to the excavation of their basins by ice action. Lake-basin production there may have been aided by warping of the earth's crust and by morainic obstruction of preglacial river courses.

Volcanic Lakes

Volcanic cones or lava flows may obstruct valleys and produce lakes. Again an example may be taken from Africa: Lake Kivu, north of Tanganyika, is of this kind: its basin was apparently drained by a northward valley to the Nile before a group of great volcanoes barred the valley and

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turned its overflow southward via Tanganyika to the Congo (pl. 26*B*). The craters of extinct volcanoes may hold lakes. Among the most famous is Crater Lake in southern Oregon, 6 miles in diameter, 6240 feet in altitude and 2000 feet deep. It is surmounted by the 1000-foot cliffs of the enlarged crater or "caldera," which is believed to have resulted from the destruction of the upper part of the original cone, to which the name Mt. Mazama has been given. Three lakes lie in the craters of as many volcanoes next north of Rome. A number of similar but larger lakes are found in the volcanic cones of Java.

River-Made Lakes

A river flowing in a serpentine or meandering course on a smooth flood plain frequently changes its course, leaving a narrow, curved lake in its previous channel (pl. 26*C*). Many such ox-bow lakes, as they are often called, are found in the flood plain of the lower Mississippi. A trunk river, which is well supplied with detritus from its headwaters, will build up or aggrade a flood plain near its banks more than at a distance to one side of them; those lower parts may then be occupied by marshy sloughs (pl. 26*C*). Such a river may, indeed, build up its flood plain so actively that its side streams which build up their plains less rapidly are converted into lake-like water-bodies near their junction with the trunk river (pl. 26*C*). The branches of the Red River of Louisiana and of the lower Danube in Russia afford examples of this kind. Basins are sometimes enclosed or divided by the fan deltas of entering streams.

Artificial Reservoirs

Reservoirs, formed by building dams across valleys, closely resemble natural lakes. California possesses many such water-bodies.

Lake-Like Bays and Lagoons

Arms of the sea, more or less completely land-locked, are also somewhat lake-like. It should be understood that the drawings presented herein are not pictures of actual lakes and landscapes, but only ideal diagrams, drawn in a highly conventionalized manner with the object of supplementing the explanations of the text.

Lakes Are Ephemeral

It follows from the above principles that lakes should be regarded as representing only a passing phase in the action of the antagonistic processes that are concerned in the shaping of the land surface. The land-shaping processes are as a rule so slow in their action that we speak, properly enough from the viewpoint of human history, of the "everlasting hills," and we take little or no account of the changes suffered by most land forms—such as Mount Sinai or the Seven Hills of Rome—during the latter part of the human period of geological time. But the student of geology must free himself of the idea that land forms are permanent, however fitting such an idea may be in the study of human history; he must strive to look on land forms as old Mother Earth herself would look upon them; that is, as forms which are, in terms of earth history, undergoing relatively rapid change.

Every element of the landscape should therefore be studied as representing a mere transitory stage of the systematic changes by which land forms pass from their earlier to their later, from their initial to their

ultimate form. In such study those water forms which we call lakes are, because of the delicacy with which water assumes a level surface, very helpful in showing where hollows or basins in the land surface occur, and the changes in the outline and area of lakes are therefore reflections of the associated changes in the form of their basins. Thus conceived, the study of lakes gains much interest to an observant traveler; and thus equipped with a general understanding of the lakes of the world, the observer is better prepared for an appreciative understanding of the lakes of his own state.

THE LAKES OF CALIFORNIA

Sources of Information

California possesses a large number of lakes and lake-like water bodies of the various kinds above explained. The account of them presented below is believed to be more complete than any other that has yet been prepared. It has been made up in part from personal observation,[2] but much more largely from the study of articles by other observers and also from the examination of large-scale topographic maps. Although much information has been thus secured, the knowledge of California lakes is as yet by no means complete. It is therefore hoped that what is here told about those which have already been examined may lead to new investigations. Many of the less known lakes are unquestionably fertile subjects for further study, such as has already been given to the Alkali Lakes of Surprise Valley by R. J. Russell, to Medicine Lake of the Modoc lava beds by M. A. Peacock, to Sierran lakes of glacial origin by Eliot Blackwelder, to the glacial and volcanic lakes of Lassen Volcanic National Park by Howel Williams, and to other lakes by various investigators whose instructive essays are cited below. In case new studies of our lakes should include good photographs, preferably from an elevated point of view so as to show the whole breadth of the water surface in its setting with its near as well as is far shore, the State Division of Mines would be glad to add prints of such views to its growing collection of landscape portraiture.[3]

Although by no means all the lacustrine water bodies of the state are named on the following pages, it is believed that examples of all the different kinds of lakes that California possesses are included. Practically all the lakes named are shown on the large, two-sheet outline map of the state, published in 1929 by the U. S. Geological Survey on a scale of 1:500,000. For the sake of brevity the location of various lakes is concisely stated in relation to neighboring mountains, rivers or other large natural features, and occasionally in relation to near-by towns or cities. Surface dimensions are given roughly in miles as taken from the topographic maps of the U. S. Geological Survey, from the charts of the U. S. Coast and Geodetic Survey and from other sources; altitudes and depths are given, not always accurately, in feet.

Lakes in Young Fault-Block Basins

The Modoc lava field, which occupies a large area in the northeastern part of California with a thickness of 4000 or 5000 feet has, according

[2] The study of lakes has long engaged the author's attention; see his essay "On the classification of lake basins," Proc. Boston Soc. Nat. Hist., vol. 21, pp. 315-381, 1882, and his shorter article on the same subject in Science, vol. 10, pp. 142-143, 1883.

[3] The address of the State Division of Mines is: Ferry Building, San Francisco 11, California.

to a recent study by Peacock,[4] been broken into several long fault blocks 10 or 20 miles in breadth, trending about north-south and crossing the northern border of the state into Oregon; the blocks have been gently and somewhat unevenly tilted so that their upraised edges form bold, little eroded scarps, from 200 to 400 feet or more in height. Three lakes occupy the down-tilted areas beneath the scarps (pl. 27*A*), and it would be difficult to find better examples of their kind. Clear Lake, one of three of that name in the state, lies 10 miles south of the Oregon line; it has been somewhat enlarged as a reservoir for irrigation and now measures 8 by 3 miles. Farther west is Tule Lake, formerly known as Rhett Lake, at an altitude of about 4140 feet. In 1884, it had an area of 184 square miles; in 1924, its area was halved; in 1930, it was "a small and shallow pond" which appeared to be vanishing. Still farther west is Lower Klamath Lake, 4175 feet in altitude and 27 by from 3 to 8 miles in size, of which only half lies in California. It also is diminishing in area, and much of it now is a reed marsh. The most probable cause for the diminution of Tule and perhaps of Lower Klamath Lake also is that their underground discharge is increasing. This, taken in connection with the steepness of their limiting fault scarps, suggests a very recent date for the faulting.

A small example of a water-filled fault-basin is seen in Marlette Lake, as described by Reid.[5] It is 2 miles long, at an altitude of 8000 feet, in the broad-topped Carson range, the uplifted mountain block next east of Lake Tahoe in Nevada. The basin is so little filled with detritus that its origin would seem to be geologically recent.

Lakes in Aggraded Fault-Block Basins

Many intermont troughs and basins produced by strong faulting or flexing are found among the uplifted fault-block mountains of the Great Basin between the Wasatch mountain range of Utah and the Sierra Nevada, and a number of them are included within the arid northeastern and southeastern corners of the Golden State. The adjoining mountains are as a rule well dissected by deep valleys and the troughs or basins are therefore heavily filled or aggraded with down-washed detrital deposits which form nearly level plains, commonly known as "valleys" (pl. 27*B*). Relatively shallow playa lakes, many of them without outlets because of the dryness of the climate, lie on the lowest part of the plains.

Playas are divided, according to Foshag, into two classes, water-tight or saline and leaky or dry. Water-tight playas are "salt encrusted areas, covered by a sticky tenacious mud when wet or a light fluffy soil when dry. During the rainy season they are often covered by shallow bodies of water and for the greater part of the year they are more or less moist. The water table seldom lies more than a few feet below the surface. The dry playas are entirely dry, only during periods of excessive or prolonged rainfall in the encircling ranges is water present on the surface for more than a few days at a time. Their surface consists of hard, smooth, sun-baked clay without visible concentration of salt."[6]

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[4] Peacock, M. A., The Modoc lava field, northern California: Geog. Rev., vol. 21, pp. 259-275, 1931.

[5] Reid, J. A., The geomorphogeny of the Sierra Nevada northeast of Lake Tahoe: Univ. California, Dept. Geol. Sci. Bull., vol. 6, pp. 89-161, 1911.

[6] Foshag, W. F., Saline lakes of the Mohave Desert region: Econ. Geology, vol. 21, pp. 56-64, 1926.

A typical example of the latter class is found in the shallow and variable Honey Lake, which lies on a broad and arid detrital plain of aggradation next below the great east-facing scarp of the northern Sierra Nevada, not far west of the Nevada line (pl. 27*B*). The scarp is believed to be the modified face of a great fault which constitutes one of the most distinctive features of the mountain range. It may therefore be believed that the Honey Lake area has been depressed and aggraded, while the strongly uplifted mountain mass was eroded. Recent slight movements on the fault are to be associated with several weak earthquakes felt there between 1880 and 1885, and in 1921.[7]

This interesting lake is 3950 feet in altitude, 15 by 9 miles in area during wet winters, and yet then only from 1 to 4 feet in depth. Its water is alkaline and the lake is adjoined by barren alkaline flats. The surrounding plain is available for agriculture only where it can be irrigated. During dry summers the lake diminishes and occasionally vanishes, leaving an utterly barren playa with a surface nearly as smooth as that of the winter lake. The region then presents an extreme contrast to its condition when it was submerged to a depth of 350 feet, some thousands of years ago, by the northwest arm of a great inland sea of very irregular outline, to which the name Lake Lahontan has been given. The shorelines made by its waves are still to be traced on the enclosing mountain slopes, but since then it has been evaporated away. One must therefore infer that the climate of the present epoch is warmer and drier than that of the epoch when Lake Lahontan was flooded. The climatic changes thus recorded probably occupied scores, perhaps hundreds of thousands of years; yet they are but a fraction of the time represented by the heavy aggradation of the Honey Lake intermont plain with detritus supplied by the down-wearing of the adjoining mountains.

In the extreme northeastern corner of the state is the flat floor of a down-faulted and heavily aggraded trough (pl. 27*B*) known as Surprise Valley (pl. 31*A*), over 40 miles long and 8 miles wide, with an altitude of about 4700 feet. It lies between the great uptilted, and immaturely dissected lava-bed fault blocks known as the Warner Range on the west and as the Hayes Canyon Range of northwestern Nevada on the east. On this flat floor lie three shallow and variable sheets of water which are named on the U. S. Topographic Map of their district as Upper, Middle, and Lower Alkali Lakes; but according to R. J. Russell, who has given an excellent description of them,[8] they are hardly known as lakes to the people who live on the surrounding plain. Two lakes may be seen from the crest of the Warner Range, looking northeast (pl. 31*A*), and southeast over the plain of Surprise Valley. Like Honey Lake, these shallow water sheets attain their greatest depth of a foot or two after winter rains; they almost or quite disappear in the summer, thus laying bare their silt beds or playas of the dry class. In winter when their water sheets are frozen over and in summer when their beds are dry and hard-baked, they may be driven over.

These lakes are bordered along their eastern or leeward shoreline by rather broad belts of salt flats, from the brine of which salt is won for local use, and sand dunes. Along their western side is a broad belt

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[7] Kemnitzer, W., The Eagle Lake earthquake of July 21, 1921: Seism. Soc. America Bull., vol. 11, pp. 192-193, 1921.

[8] Russell, R. J., The land forms of Surprise Valley, northwestern Great Basin: Univ. California, Pub. Geog., vol. 2, pp. 323-358, 1927.

of grasslands, subject to temporary flooding from the mountains in the wet season. Here, marked by groups of willows, numerous springs bring forth the ground water that is fed by rainfall on the Warner Range. Some of the springs are hot; others bring fine silt to the surface and build small mounds around their vents, locally known as "mud volcanoes." The grassland belt is the best farming area of the intermont plain; as seen from the mountains its fields have a checker-board appearance, in pleasing contrast to the uncultivated and almost valueless adjoining surface.

Like other lakes of their kind in the Great Basin these Alkali Lakes, the vague shorelines of which migrate with the winds, are the successors of an ancient and much larger lake, which flooded a large part of the intermont basin plain and to which the name Surprise Lake has been given. Its shorelines on the mountain slopes show it to have had a length of 70 miles and a depth of 550 feet. The climate then must have been cooler and rainier than now.

Goose Lake, as described by R. J. Russell,[9] is another shallow water sheet, which occupies, at an altitude of 4800 feet, a large part of a moderately down-faulted trough below the western slope of the above-named Warner Range. It measures 30 by 10 miles, but one-third of its length extends into Oregon. A shallow gorge eroded through the lava beds on the south indicates that the lake formerly had a somewhat persistent discharge to Pit River, which flows westward through the highlands between Mount Shasta and Lassen Peak to the Sacramento; but at present the lake overflows only when the water is brushed southward by a strong north wind, as happened in 1910.

Farther south, close to the eastern base of the Sierra Nevada lies Mono Lake, 6420 feet in altitude and 12 miles in diameter. This lake has been described by I. C. Russell.[10] It is believed to occupy a basin of depression, produced by down-faulting with relation to the up-faulting of the adjoining mountain range, but the enclosure of its waters may be due, at least in part, to volcanic barriers. As in the case of the Nevada lakes above described, a much larger lake, known by its high-standing shore lines, formerly occupied the basin in which Mono Lake now stands. The beauty of the present lake is much enhanced by the grandeur of the mountain scenery on its western side. The famous Tioga Road makes its descent there from the Sierra crest in a deep ravine. A considerable area south and southeast of the lake is covered with volcanic cones and lava flows, which have presumably diminished the extent that the lake might otherwise have. A volcanic island in the lake and several glacial moraines near it on the west will be referred to below in the sections on lakes of volcanic and of glacial origin.

Still farther south where the climate is even warmer and drier, a number of dry lake-beds on the lowest part of many intermont plains may be here instanced as showing that lakes were formerly more abundant than now, and as thus indicating the cooler and moister climate of that earlier time. South of Mono Lake 110 miles in Owens Valley and again at the eastern base of the Sierra Nevada, is the shallow Owens Lake, 3569 feet in altitude, 15 by 9 miles, formerly larger, now mostly reduced to

[9] Russell, R. J., Basin Range structure and stratigraphy of the Warner Range, northeastern California: Univ. California Dept. Geol. Sci. Bull., vol. 17, pp. 388-496, 1928.

[10] Russell, I. C., Quaternary history of Mono Valley, California: U. S. Geol. Survey Eighth Ann. Rept., pp. 281-394, pls. 17, 19, 21, 1889.

a saline incrustation: this is therefore a playa of the saline class. To the southeast is the dry plain or playa of China Lake, 2124 feet in altitude, 7 by 2 miles; still farther east between the Argus and Slate Ranges, is Searles Lake, 11 by 6 miles, 1623 feet in altitude, now heavily crusted over with a sheet of salt but containing a body of brine below, in consequence of which it has become the seat of an important chemical industry: this is another example of a saline playa. Again farther east, on the desert floor of the intermont depression known as Panamint Valley between the Slate and Panamint Ranges, is Dry Lake playa, a white plain of saline clay, measuring 17 by 2 or 3 miles at an altitude of 1050 feet; another playa lies farther north in the same valley. Beyond Panamint Valley is the more famous Death Valley, of similar nature and again containing a playa of saline clays, but lying for the most part below sea level.

All of these now extinct lakes were, in the glacial period, on the course of the then enlarged Owens River, and each one of them except the last named then expanded to much greater area and depth than its saline successor of today and rose to the level of the lowest sag in the barrier to the east: thus each lake, as Gale, cited below, was the first to point out, overflowed to the next lower member of the series. At the level of each sag of overflow a shore line was more or less clearly marked around the lake by wave-built beaches, still discontinuously traceable. The lake of Death Valley, believed to have been fed by the overflow from Panamint Lake across Wingate Pass, does not appear to have risen to a sag of overflow as it was the farthest member of the series; hence its level, being dependent on inflow and evaporation, fluctuated up and down. Its faint shore lines have been detected at a number of points and indicate that it had a length of two or three score miles when at its highest level.

In the southern part of the Inyo Range, next east of the southern Sierra Nevada, are two down-faulted and aggraded "holes," known as Saline and Deep Spring Valleys. In each of them a saline lake or incrustation lies near the scarp of down-faulting. The first has been described by Gale [11] and by Knopf [12]; the second by Miller.[13]

Many playas of the dry kind, representing vanished lakes mostly of moderate size (pl. 31*B*), might be mentioned as occurring in the arid southeastern part of the state. Like all their fellows these playas are covered with a very shallow sheet of water after heavy rains, and their clay floors are then impassable; but when the water is evaporated in the dry season the clay surface is firm and smooth, except where ridged and hard-baked ruts remain to mark the path of adventurous cars. One of the playas, known by the generic name of Dry Lake, 17 by 2 miles, is crossed by the Santa Fe railroad in its traverse of the northern part of the Mojave Desert. Another known as Bristol Lake, on the same railroad line farther east, is varied by the invasion of a black and ragged lava flow from a small volcanic cone on the west. Two smaller playas north of that railroad are crossed by the Cave Springs road to Death Valley. Others are too numerous to specify. It is on the level surface of a dry playa that the deceptive imitation of a lake, known as a "mirage," is developed on calm summer days. It is due to the super-heating of a thin layer of air next to the

[11] Gale, H. S., Salt, borax and potash in Saline Valley, Inyo County, Cal.: U. S. Geol. Survey Bull. 540, 1914.

[12] Knopf, Adolph, A geologic reconnaissance of the Inyo Range * * *: U. S. Geol. Survey Prof. Paper 110, 1918.

[13] Miller, W. J., Geology of Deep Spring Valley, California: Jour. Geology, vol. 36, pp. 510-525, 1928.

ground, so that when it is looked at from one side the light of the farther sky is reflected from it to the observer. As such reflection is a normal characteristic of true lakes, an inexperienced observer is likely so to misinterpret it in the desert.

Lake Elsinore, 5 by 1 or 2 miles, 1220 feet in altitude, is a shallow, brackish and variable water sheet lying in a faint depression at the highest part of the long, aggraded fault trough next northeast of the Santa Ana Mountains, 60 miles southeast of Los Angeles. Whether the shallow basin of the lake is determined by small and recent movements on faults, or by detrital fans washed in from the enclosing mountains has not yet been fully decided. The lake occasionally rises enough, in years of exceptionally heavy rainfall, to overflow northward by Temescal Creek along the fault trough to Santa Ana River. The scanty water supply of its district is made the most of in developing its scenic attractions.

Ancient Lakes of Intermont Basins

As the foregoing pages have presented accounts of playa lakes which vary with the seasons and of ancient lakes which indicate past variations of terrestrial climate through thousands of years, a brief mention of certain basin plains may be added which appear to indicate the occasional occurrence of still more ancient lakes. The part of the Sierra Nevada west of the above-described Honey Lake has been explained by Diller [14] as consisting of several west-sloping fault blocks with east-facing and more or less modified fault scarps (pl. 27*B*). Northeastermost is Diamond Mountain block, some 40 miles in length, with a strong scarp, 2000 feet high, overlooking the Honey Lake plain. The surface of the block slopes gently southwestward for some 20 miles into a long depression at the base of the next or Grizzly Mountain block; and that block, also sloping southwestward, is followed in its turn by the larger Claremont block which slopes down to the vast plain of the Great Valley. The inter-block depressions are aggraded with detrital plains, known as Indian and American Valleys.[15] Lakes may have existed there intermittently during the time of slow faulting but none are present today. A larger example of an intermont basin which may have held a shallow lake at times during its aggradation is found in the so-called Sierra Valley, a broad plain which lies southeast of Indian and American Valleys and which will be described below in connection with Lake Tahoe after the section on volcanic lakes.

Similar inferences as to the former occurrence of temporary lakes may be made with respect to several smaller intermont basin plains in the northern Coast Ranges, such as Potter and Long Valleys, as well as to the somewhat larger basin-plain now mostly submerged beneath the waters of Clear Lake, 100 miles north of the Golden Gate, of which further account is given in the second-following section. All of these plains may have been intermittently flooded by shallow lakes during the slow downflexing or down-faulting of their basin floors, but there is no sufficient reason for thinking that the basins were so suddenly produced that they at first held deep lakes which were then, after their rapid production ceased, slowly filled in with detritus and converted into plains as their outlets were cut down. Whatever lakes occupied the basins are best

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[14] Diller, J. S., Geology of the Taylorsville region, California: U. S. Geol. Survey Bull. 353, 1908.

[15] A view of the Indian Valley plain and of the dissected fault scarp to the west of it is given by Diller in Plate LI of his report on the Geology of the Lassen Peak district, U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 395-432, 1889.

interpreted as shallow and temporary features compared to the associated fault-block mountains and basin plains.

The same statement holds good for the many longer and larger intermont basin plains of the southern Coast Ranges, of which typical examples are found in the Panoche and the Quien Sabe Valleys, the first measuring 10 by 4 miles at an altitude of 1300 feet, the second 8 by 1 or 2 miles at an altitude of 1600 feet; both are drained by small streams through mountain gorges. Apparently on account of the southeastward decrease of rainfall, one of the larger southern examples, known as the Carrizo Plains, is peculiar in lacking a stream outlet. It is enclosed by a broad mountain mass on the west and on the east by the Temblor Range, the latter being one of the latest linear upheavals by which the breadth of the Coast Ranges has been increased at the expense of the Great-Valley plain. The smooth, treeless Carrizo surface, mostly given over to wheat fields, has been built up in faintly concave form by the inwash of detritus from the valleys eroded in the inclosing ranges; so that it now has a length of 40 miles, a width of 5 miles and an altitude of from 1950 feet at its middle to about 2600 at the ends. Over its lowest, medial part is spread Soda Lake, 5 miles long; a shallow water sheet after winter rains, a white and barren desert during the hot and dry summers. It lies near the western border of the plain because of the more abundant inwash of waste from the Temblor Range on the east.

Sag Ponds

Here and there along the Elsinore fault or rift and still more frequently along the more famous San Andreas rift, a slight movement on which caused the San Francisco earthquake of 1906, numerous little water-holding depressions, known as "sag ponds," mark the sites of local subsidences. One of the largest of its kind is Lake Elizabeth, about 2 miles long, on the San Andreas rift in the western part of the Mojave Desert, 50 miles northwest of Los Angeles. An unnamed sag pond, a mile in length, occurs on a rift at the base of the recently up-faulted El Paso Range, 6 miles northwest of Randsburg.

Landslide Lakes

The chief California lake of this class is Clear Lake,[16] which floods the greater part of an intermont basin plain in the northern Coast Ranges. It has given name to the county, in the center of which it lies. Long previous to the production of the lake, the plain, measuring about 25 miles northwest-south, by 15 miles in greatest width, was drained by two outflowing streams, the divide between which may have been marked by low mountain spurs near the lake middle. One of the streams (Cold Creek) had cut a deep gorge westward through an enclosing range to Russian River, which led it to the Pacific 55 miles north of the Golden Gate; the other (Cache Creek) had cut a longer and deeper gorge eastward through the opposite range, which led to the Sacramento and thus to the head of San Francisco Bay. After a time the eastern stream was crossed near its gorge entrance by a small lava flow, and its headwaters were thus diverted to the western stream.

At a still later date a landslide, descending only a few centuries ago from the southern side of the western gorge near its mid-length,

[16] This account is condensed from an unpublished study of Clear Lake by the author. Much assistance has been received from Olaf P. Jenkins, Chief Geologist, Division of Mines. It was he who first found the trench through the lava flow, which has proved to be of so great significance in the history of the lake.

filled it up for a mile or more to a higher level than that of the lava flow near the far end of the basin plain. The obstruction was so effective that a lake, fed by the streams that flowed into the basin, slowly rose higher and higher behind the slide, spreading over more and more of the plain, until it overflowed across a sag in the lava flow. The overflowing stream thereupon cut a trench (Redbank Gorge) across the flow, thus lowering the lake about 60 feet below its highest level, giving it a discharge through the eastern gorge, and re-enforcing the previously beheaded eastern stream (Cache Creek). The reduced lake now stands at an altitude of 1310 feet, with a size of 19 by 8 miles and a maximum depth of about 50 feet. Two narrow eastern arms are separated from the main western body at a picturesque Narrows (pl. 39), near the lake midlength. Had there been no outlet for the lake through the eastern gorge, the lake would probably have risen until it overflowed across the landslide in the western gorge and its outlet stream would very likely have washed away most of the slide in a destructive flood centuries ago, thus draining the lake and laying bare again the intermont basin plain. But such western overflow was effectively prevented by the presence of the eastern gorge. The landslide is of so enormous a volume that its removal by surface rills or leakage of ground-water is out of the question.

Since the formation of the lake its slender arm that at first occupied the part of the western gorge back of the landslide has been cut off from the main body of the lake by the broad delta of Middle Creek, which comes from the north; and the arm has been further shortened by the delta of Scott Creek, which entered it from the south. Its short remainder is now divided by the combined deltas of two wet-weather side streams, thus forming the picturesque little Blue Lakes (pl. 33), beautifully enclosed by the steep sides of the gorge. These lakelets, therefore, belong in the class of lakes, the basins of which are barred by deltas, as will be told in a later section.

Clear Lake was artificially modified 20 years ago by the building of a 30-foot dam at the entrance to the eastern gorge and by the blasting out of a rocky barrier to a few feet greater depth near the entrance of the eastern outlet stream into the trench through the lava barrier, with the object of storing greater volume of water supplied by the winter rains and of withdrawing it to lower than ordinary lake level for irrigation of rice fields in the Yolo basin of the Sacramento in the summer. In consequence of these changes, the lake surface now usually stands a few feet below the level of the shore beaches that were formed before the changes were made. Unfortunately, the moderate rainfall of the region, 25 or 30 inches a year, does not supply the inflowing streams with much more water than is lost by evaporation, 53 inches in a year, from the lake surface, and therefore the outflow available for irrigation is usually small.[17]

The various changes that have taken place in the drainage of the basin have had a curious effect on the distribution of river fish. In consequence of the lava flow by which the head of the eastern stream was cut off and diverted to the western stream, one must infer that various species of fish belonging to the Sacramento system were transferred to the Russian River. This inference finds support in a study by Snyder who, nearly a quarter-century before the existence and the effects of the lava flow were discovered, pointed out that the fish of Russian River are like those

[17] Chandler, A. E., Water storage on Cache Creek, California: U. S. Geol. Survey Water-Supply Paper 45, 1901.

"of the upper courses of the streams tributary to the Sacramento which flow from the western side of the Great Valley, the channel forms common to the main river [Sacramento] being absent" from the Russian River; and he therefore concluded that "the fish fauna of the Russian River was probably derived from the Sacramento," for "the Sacramento, a vastly larger and probably older system, not only contains all the [12 indigenous] fluviatile species known from the Russian River, but also others not there represented."[18] If the history of Clear Lake involved only its blockade by the landslide in the western gorge and the resulting shift of west-flowing stream through the eastern gorge to the Sacramento system, the above prophetic statement would have lacked confirmation; but the discovery of the lava flow and its effects confirms the prophecy by giving it a sound geological foundation.

A fine highway, ascending the lower part of the western gorge from Russian River valley, surmounts the landslide, skirts the Blue Lakes, crosses the delta plain of Middle Creek, follows the north shore of the main body of the lake, passes the Narrows and continues along the northern and shorter one of the two eastern arms. A side road, zigzagging up the mountain slope north of the main body affords a fine view of the lake and of the Konocti group of volcanoes, which reach altitudes over 3500 feet, adjoining the longer or southeastern lake arm. A considerable area of the basin plain, known as Big Valley, adjoining the main body of the lake on the south, is largely devoted to fruit raising.

This fine lake, the only lake in the northern Coast Ranges, is perhaps even more largely resorted to by summer visitors than Lake Tahoe in the Sierra Nevada. Its attractive scenery is therefore of a considerable esthetic value to the state, while its fisheries are of growing economic value. Moreover, in consequence of its production Lake County has become the home of many waterfowl which would otherwise not remain there.

Several other smaller lakes of landslide origin occur in the deeply eroded valleys of the Warner Range, already referred to as forming the western boundary of Surprise Valley in the extreme northeastern corner of the state. They have been well described by Russell,[19] who explains that their formation is favored by the occurrence of weaker volcanic beds under a capping of resistant basalt, so that the basalt, forming a "rim rock" at the top of the valley sides, is sapped by the more yielding beds below it. One of these small lakes which, like the above described much larger fault-basin lake some 40 miles farther west, repeats the name of the still larger landslide lake in the northern Coast Ranges, measures only one-half by one-eighth of a mile, with a depth of 90 feet; it stands at an altitude of 5750 feet in a canyon 1000 feet deep in the western slope of the range. Two landslides, one from each side of the canyon, form its barrier; their scars are fresh-looking and the delta of the inflowing stream is small; hence the age of the lake is perhaps not over a century. Blue Lake, 10 miles farther south, is of similar and recent origin, but it is barred by a single slide. These two lakes drain to Pit River. Lost Lake lies in a sharply eroded canyon on the eastern slope of the same range at an altitude of 7400 feet; it is about 1700 feet in diameter; its delta is 50 percent larger than its own area, and the scar of its landslide, a mile in length, is less fresh than those of Clear and Blue

[18] Snyder, J. O., The fauna of Russian River, California, and its relation to that of the Sacramento: Science, vol. 27, pp. 269-271, 1908.

[19] Russell, R. J., Landslide lakes of the northwestern Great Basin: Univ. California, Publ. Geog., vol. 2, pp. 231-254, 1927.

Lakes. The outlets of these lakes all cascade down over the great boulders of their barriers.

Jess Valley is also, according to Russell, the filled-in and drained bed of a much older and larger landslide lake in the valley of Pit River, between Clear and Blue Lakes, where that river, passing from the western base of the Warner Range, cuts a gorge through another up-faulted block of lava beds of less altitude. The nearly level surface of the valley measures 6 by $2\frac{1}{2}$ miles at an altitude of 5300 feet. Its obstructing slide filled the gorge for half a mile and is estimated to contain 45,000,000 cubic yards of detritus. Several other meadows of similar origin are found farther down the gorge; but they are now trenched by the river, so that their remnants form terraces on the gorge walls. The same experienced observer reports that Eagle Lake, 30 miles northwest of Honey Lake, 5115 feet in altitude and 12 by from 2 to 4 miles in size, appears to be barred on its southeastern side by a landslide; if so, it would rank next after Clear Lake. He adds that this lake rises and falls without regard to rainfall, and that when it sinks numerous springs flow actively from the outer slope of its apparent barrier and supply streams that reach Honey Lake. This suggests that the barrier is of porous nature, as a landslide might well be, and that the water passages through it are intermittently closed and opened.

The small Kern Lakes, in the southern part of the remarkably rectilinear, north-south canyon of Kern River, west of Mt. Whitney in the southern Sierra Nevada, have been described by Lawson.[20] The southern one was originally barred by a rock slide which came down from the eastern wall of the canyon about 100 years ago and obstructed the canyon floor for a mile of its length; but the lake, now less than a mile across, has been much diminished by in-washed detritus. Kern River, continuing through the lake, has barred off its course by the high edge of its flood plain. The northern lake, a mile farther upstream, diminished by Kern River delta to a half-mile diameter, is separated from the lower lake by the detrital fans of two small streams from the east: it is believed that these fans were much increased in size in 1868, and that the separation of the upper from the lower lake dates from that year. Mirror Lake in the Yosemite Valley is also of rock-fall origin and will be described in the latter part of the next section.

A small lake, now extinct, was formed by a landslide in Grapevine Canyon, where the Ridge Road leading from Los Angeles northward to the central part of the state enters the southern part of the Great-Valley plain. This canyon is cut in the mountains which there curve around from the Sierra Nevada on the east to the Coast Ranges on the west; and the slide came from the mountain flanks on the west side of the canyon mouth. The uneven surface of the down-creeping mass is distinctly unlike the smooth and undisturbed slopes on either side of it. The lake which rose back of the slide has long since been filled with detritus, through which as well as through the slide itself a gorge has now been eroded. The thousands of travelers who daily follow the Ridge Road cross over the lower part of the slide, where the impetus of its flow banked it up against the east side of the canyon mouth; the road there makes a winding descent to the gently sloping "fan" of flood-washed stony and bouldery detritus that slants far forward on the vast plain. Another ancient slide seems to have blocked the stream farther up the same canyon near old Fort Tejon.

[20] Lawson, A. C., The geomorphogeny of the upper Kern basin: Univ. California, Dept. Geol. Sci. Bull., vol. 3, pp. 291-376, 1904. See pp. 343-345.

Two small landslide lakes are known in the northern corner of Lassen Volcanic National Park. One, Manzanita, originated according to Williams, cited below, about 200 years ago when a slide known as the Chaos Jumbles descended from Chaos Crags and blocked the valley of Manzanita Creek;[21] another, Reflection, lies in a hollow of the extremely rough landslide surface.

Small lakes or ponds of another kind lie at the head of valley-side landslides where a hollow is formed because the downward movement of sliding mass is commonly faster and farther at its under than at its upper surface, so that its head is tilted backward (pl. 27*C*). The irregularity of the down-sliding is often shown by diversely tilted overthrown trees. Large slides sometimes involve a great, slab-like mass that stretches half a mile or more along a mountain side and nearly or quite as far down the mountain slope (pl. 27*C*). In consequence of its somewhat irregular descent, the smooth forms of ordinary degradation are changed to curiously disorderly forms. At the head of these greater slides, many small, pond-holding hollows may be formed. Such ponds are short lived, but they may linger longer than the larger ponds that are held back on valley floors by the bulging front of slides, because such ponds are soon drained away by the valley stream.

Landslides of this kind are numerous in those parts of the Coast Ranges where serpentine rock prevails, for that rock is prone to slip down from a mountain side after a valley is deeply eroded beneath it. Valley sides subject to sliding should evidently be avoided as far as possible by roads, pipe-lines, towers for electric power wires, and other structures for which stable foundations are desirable. The disorderly surface of slides may still be recognized years after any little ponds at their head have disappeared. However, a number of ponds still remain above the slides that abound on the slopes of Mustang Ridge, northeast of Peachtree Valley, which is in its turn northeast of the much larger Salinas Valley in the southern Coast Ranges.

According to a personal communication from Dr. J. H. Maxson of the California Institute of Technology, several landslide ponds occur in the serpentine areas of the Klamath Mountains in the northern part of the state.

Lakes of Glacial Origin

Glaciation of California Mountains

Most of the larger lakes named in the preceding sections lie on relatively low ground, presumably because they are associated with down-faulted areas or with down-sliding valley sides. The numerous lakes of the kind now to be described are found on mountainous highlands where their basins have been produced by the erosive action of great glaciers which covered considerable spaces in the higher parts of the Sierra Nevada and smaller spaces of other California mountains. That remarkable episode occurred in the glacial period of recent geological time, a period of cooler and snowier climate on mountains that is believed to have been contemporaneous with the cooler and moister period when lakes were formed on interior desert lowlands.

In order to appreciate the importance of glaciation in respect to lake production, it should be understood that, in preglacial time, there were in all probability no lakes on the Sierran highlands. The reason for this is

[21] A fine view of the lake is given in the frontispiece of Day and Allen's report on Lassen Peak, cited below.

that the highlands had then been long subjected to the ordinary erosional processes of weathering and streaming, which would have destroyed any lakes that might have been produced there in earlier times by faulting as described on foregoing pages, or by ancient volcanic action as will be described on following pages. Lake Tahoe is hardly an exception to this rule, for although produced by a combination of faulting and volcanic action, as will be told below, it is not on the highlands but occupies a deep trough below them.

The great Sierran glaciers of that time, the area of which has been mapped by Blackwelder,[22] had their sources in lofty valley heads where heavy snows were collected below the mountain summits and transformed into ice. The many separate glaciers that had their source in the high valley heads of each of the Sierran river systems united in broad sheets as they slowly advanced down the highlands of the western Sierran slope, but the sheets were irregularly interrupted by spurs and mounts that rose from the highlands to a greater height than the ice thickness. Then the sheets narrowed into faster moving ice tongues as they were drained down the previously eroded trunk valleys. While the descent was in progress the glaciers were melting to smaller and smaller volume as they reached lower and lower levels of warmer climate. By reason of the more extended area of their gathering grounds and of the larger number of their converging branches, the glaciers of the long western slope had greater size and pushed their ends down to lower levels than those on the shorter and steeper eastern slope of the mountains, which are diagrammed in plate 25. Thus the Tuolumne glacier, west of Mono Lake, extended for 34 miles along the crest of the range and ended 35 miles southwest of the crest; while for the San Joaquin glacier, south of that lake, the corresponding dimensions are 52 and 25 miles. On the steeper eastern slope, the measures along the crest and down the slope from it were much smaller.

Two Epochs of Glaciation

Two terminal moraines are shown in each glaciated valley of plate 25. The lake that may have once occupied the earlier formed, outer basin has been filled by inwashed detritus and converted into a plain or meadow. The inner basin still holds a lake. Such is very commonly the case in the glacial troughs of the Sierra Nevada. It is inferred from this and from other evidence of a similar nature that there have been at least two epochs of glaciation. Critical studies of this kind in various parts of the world have indeed shown that the glacial period was composite in the sense of including several alternations of colder glacial epochs and milder interglacial epochs. An excellent discussion of this problem for the Sierra Nevada is given by Blackwelder in his essay cited below; he there shows that, besides two later glacial epochs, which he calls the Tahoe and the Tioga epochs (pl. 25), there were two earlier glacial epochs, the records of which are much modified and obscured by later erosion. The lakes produced in the latest or Tioga epoch are the chief subject of the following pages; but first the relation of the recent Tioga glaciers to the less recent Tahoe glaciers may be briefly stated.

There are four chief points to be considered. First, the Tahoe glaciers of the Sierra Nevada were longer than the Tioga glaciers and extended farther down their valleys (pl. 25). Thus while the largest Tioga glaciers

[22] Blackwelder, Eliot, Glacial and associated stream deposits of the Sierra Nevada: California Div. Mines Rept. 28, pp. 303-310, 1932.

ended at levels of about 6000 feet on the western and about 7000 feet on the steeper eastern slope of the mountains, the Tahoe glaciers ended perhaps 1000 feet lower. For example, in the Tahoe epoch the branch glaciers of Tenaya and Merced Canyons joined to form the great trunk Yosemite glacier, which continued about 7 miles and ended at about the level of 4000 feet near the end of the great cliff-walled trough, the shape of which was largely produced by the intense glacial erosion of a pre-existing narrower and shallower valley, as Matthes has so well shown.[23] But in the Tioga epoch, the branch glaciers each ended in its own trough where lakes of the same names are now found, about 8 miles above the trough junction.

Second, the Tahoe moraines are many times larger than the Tioga moraines; some of the largest measure nearly 1300 feet in height. Third, by reason of their greater age, the cliffs of the Tahoe cirques are weathered to somewhat subdued forms, the cirque-floor basins are occupied by meadows, and their trough-end lakes are in nearly all cases now converted into detrital plains. Fourth, whatever lake basins the Tahoe glaciers produced at higher levels than the Tioga moraines are not now to be distinguished from the basins now occupied by the lakes of the Tioga epoch.

The following pages, therefore, refer chiefly to lakes produced in the Sierra Nevada by the later Tioga glaciers, even if their work consisted largely in cleaning out detritus-filled rock basins of earlier Tahoe production. Some brief statements concerning extinct lakes of the Tahoe stage will be given at the close of this section.

All the California lakes of glacial origin are of relatively small size, but many of them are of great beauty; and as they are often closely associated with the superb scenery of the high Sierra they are greatly enjoyed by lovers of outdoor life when the hot summers of the lowlands prompt ascent to the cooler mountains. As the glacial lakes of the state far outnumber all others, much has been written about them. By far the best illustrations of these lakes, many of which are accessible only to mountaineers, are to be found in the annual volumes of the Bulletin issued by the Sierra Club of San Francisco, in which they are pictured in an incomparable series of photographs.[24] The loftiest glacial lakes occupy basins in cirque floors; these will be first described. Next will come those somewhat irregular lakes which lie at intermediate altitudes on trough floors or on the open Sierran highlands. Lowest are those which fill the terminal overdeepening of the enlarged valley-troughs, where they are partly enclosed by terminal moraines; these are most frequently visited.

Lakes in Glacial Cirques

Cirque lakes occupy shallow rock-basins in the floors of the great cliff-walled cavities excavated at the heads of glacial troughs, somewhat in the form of enormous quarries, 500 or 1000 feet deep and half a mile or a mile across. They abound in the high Sierra, where they are found below the loftier summits at altitudes of from 8000 to 10,000 feet. There and more strikingly in the northern and southern part of the range, where the mountains are not so high, cirque lakes were developed best on northeastern slopes, where snow drifting was favored of the westerly

[23] Matthes, F. E., Geologic history of the Yosemite Valley: U. S. Geol. Survey Prof. Paper 160, 1930.

[24] Among many others the following views are especially fine: Sierra Club Bulletin, vol. VII, Pls. 31, 40; vol. VIII, Pl. 6; vol. IX, Pls. 16, 20; vol. X, Pl. 226.

winds and where snow melting by sunshine was least effective. The peaks above such lakes are therefore unsymmetrical, being more rounded on the southwest slope and deeply cliffed on the northeast.[25] The cirques of the earlier Tahoe epoch, not reoccupied by the Tioga glaciers, are now, as above noted, weathered to somewhat dulled forms; their floors are cluttered over with talus from their walls and their lakes are converted meadows. Those occupied by the later and smaller Tioga glaciers are as bare as if recently abandoned by the ice.

Where several cirques are excavated opposite each other in the radiating valleys of a massive, dome-like mountain of preglacial sculpture, the cirque lakes are separated from one another by high spurs, the upper parts of which are narrowed into saw-tooth pattern, while the central summit is reduced to a sharpened peak (pl. 28*A*); but where several preglacial valleys, heading in a group of mountains, converge and join in a trunk valley, the cirque-headed troughs have a similar converging arrangement and the smaller ones ''hang'' over the larger one (pl. 28*B*); here all the cirque lakes of such a group are rather closely associated. But it should be understood that vast as is the work of glacial sculpture in the high Sierra, the erosional work of ordinary weathering and streaming by which the mountains had been given their preglacial form was vaster still.

It is in intimate association with these profoundly sculptured mountain forms that cirque lakes (pl. 35) should be studied. If taken alone they cannot be appreciated, for their little basins are but a subordinate part of the great cirque-headed, cliff-walled troughs in which they are contained. The basins differ in no significant respect from the rest of the gigantic excavation, except that they are scoured to slightly greater depth so that they hold water. The same principle holds true, though perhaps less manifestly, in the study of all the other lakes of the state; it should be applied to the fault-basin and the landslide lakes already described and to the volcanic, river-made and other lakes to be detailed below. All are but items in the evolution of the landscape which they for a time adorn.

The Tehipite, Mount Whitney and several other sheets of the U. S. Topographic Map show many striking examples of lakes in trough-head cirques excavated in the dome-like masses of the high Sierra. Regarding the concave cirque heads, W. D. Johnson, a skillful topographer, wrote in homely fashion: ''These sharp outlines were suggestive of nothing so much as the scattered remnants of a sheet of dough on the biscuit board, after the biscuit tin has done it work.''[26] A fuller discussion of these remarkable mountain forms is given by Lawson.[27]

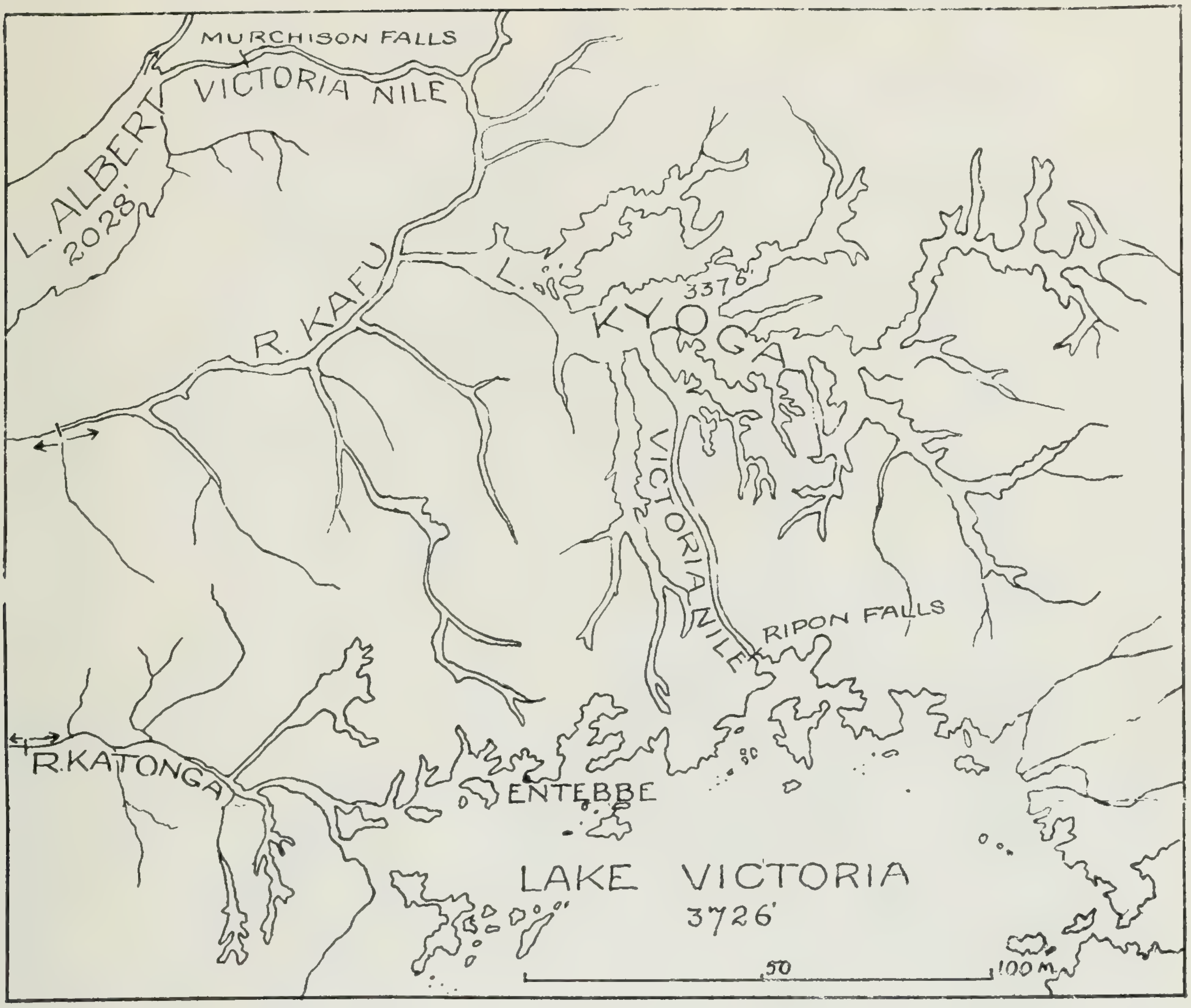
Sometimes a series of small lakes, like beads spaced on a string, is seen occupying a succession of rock basins beginning in a cirque floor and continuing down stream from it. It is to be presumed that the convex rock sills between the basins were more resistant to glacial erosion than the basin rocks; the greater resistance may be due to the number and attitude of the joints in the rock quite as well as to variations in its composition.[28] Such series of lakes are to be seen at the headwaters of Illi-

[25] Gilbert, G. K., Systematic asymmetry of crest lines in the high Sierra of California: Jour. Geology, vol. 12, pp. 579-588, 1904.

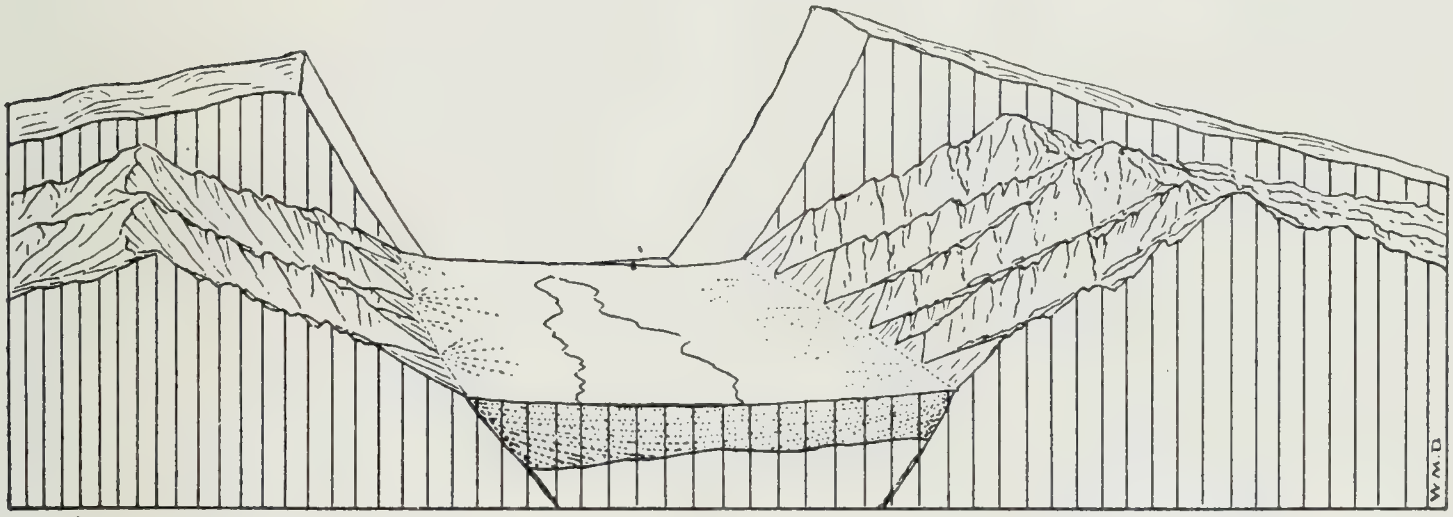
[26] Johnson, W. D., Grade profiles in alpine crests: Jour. Geology, vol. 12, pp. 571-578, 1904; reprinted in Sierra Club Bulletin, vol. 5, pp. 271-278, 1905.

[27] Lawson, A. C., The geomorphogeny of the upper Kern basin: Univ. California, Dept. Geol. Sci. Bull., vol. 3, pp. 291-376, 1904; see pp. 357-362. This article gives in Pl. 42 an excellent view of a fine cirque lake next southwest of Mount Whitney, the highest summit of the Sierra Nevada.

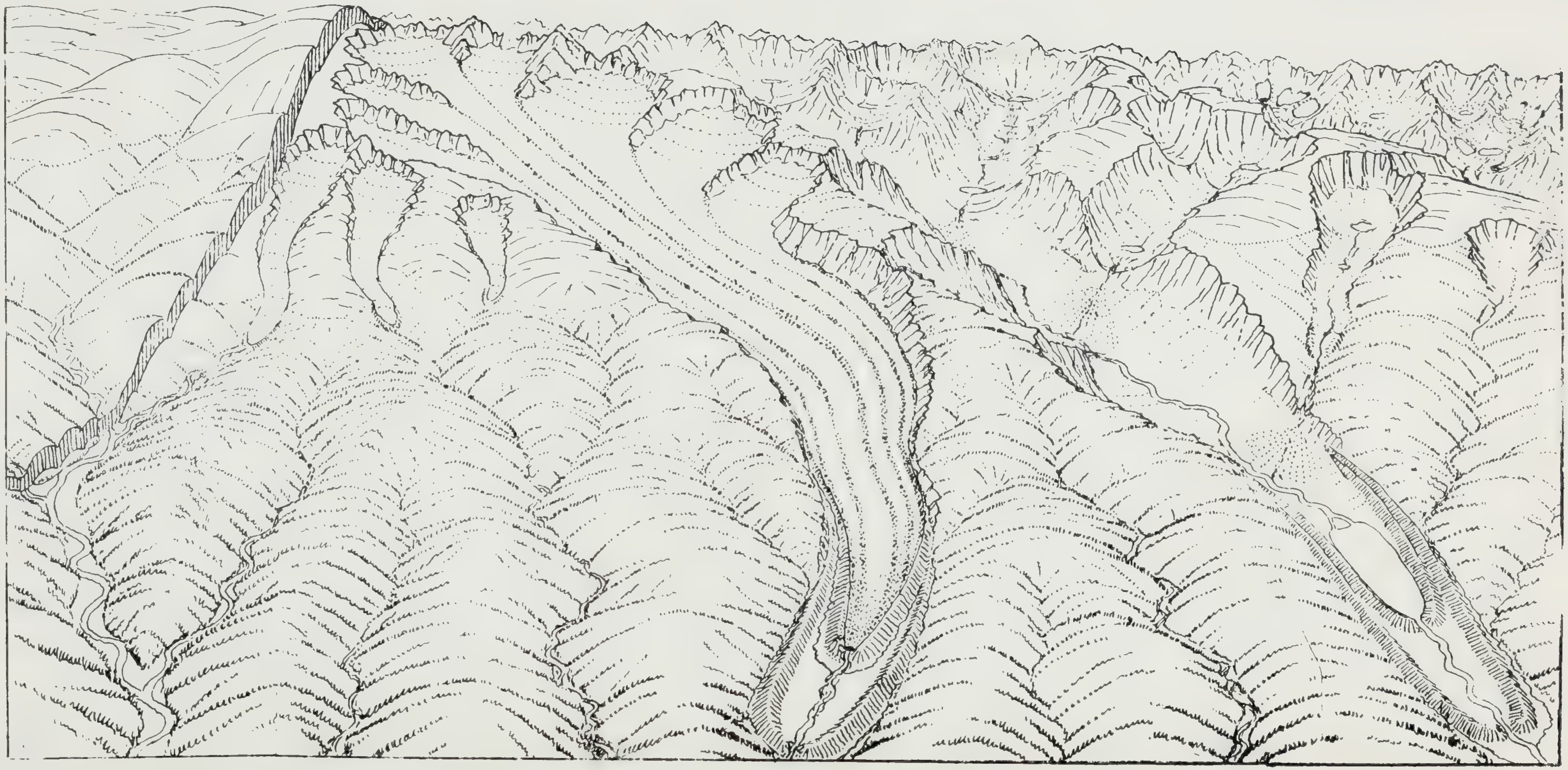
[28] A striking view of a rock sill is given in pl. 4 of Johnson's article above referred to.



A, LAKES KYOGA AND VICTORIA, CENTRAL AFRICA
Reduced from a map in report of E. J. Wayland, Director, Uganda Geological Survey.

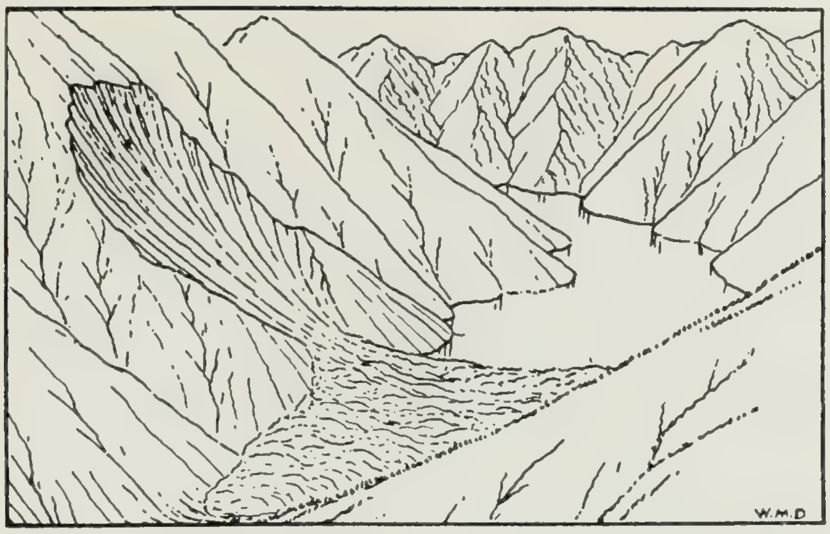


B, DEPRESSED FAULT ROCK
Background, between two upheaved fault rocks ; foreground, the same, after a considerable period of erosion and deposition.

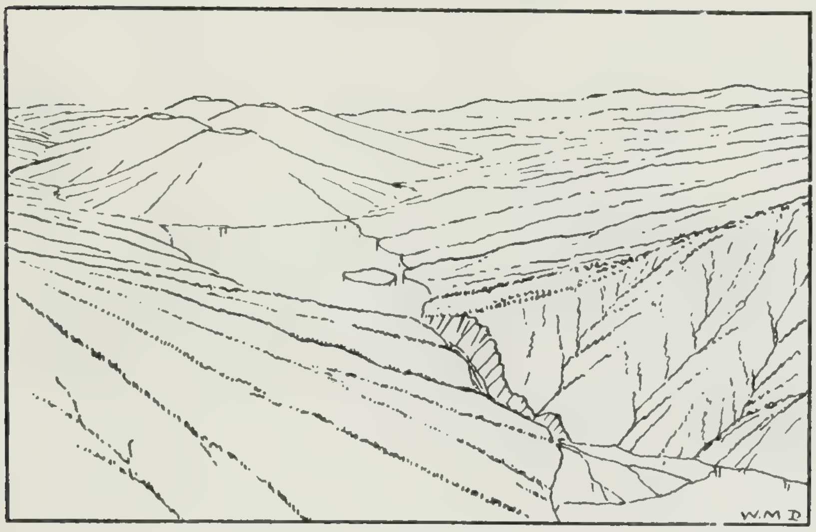


THREE-STAGE DIAGRAM ILLUSTRATING GLACIAL SCULPTURE OF MOUNTAINS

On the extreme left, a non-glaciated mountain mass, with rounded spurs and narrow valleys, the work of ordinary erosional processes, chiefly weathering and streaming. Across the middle, same kind of mountains after they have been well modified by the glaciers which still occupy their valleys. On the right, the same, after the glaciers have disappeared, so that the cirques and troughs which they excavated are exposed to view. Many small lakes are there seen, although no lakes existed in the mountains on the extreme left.

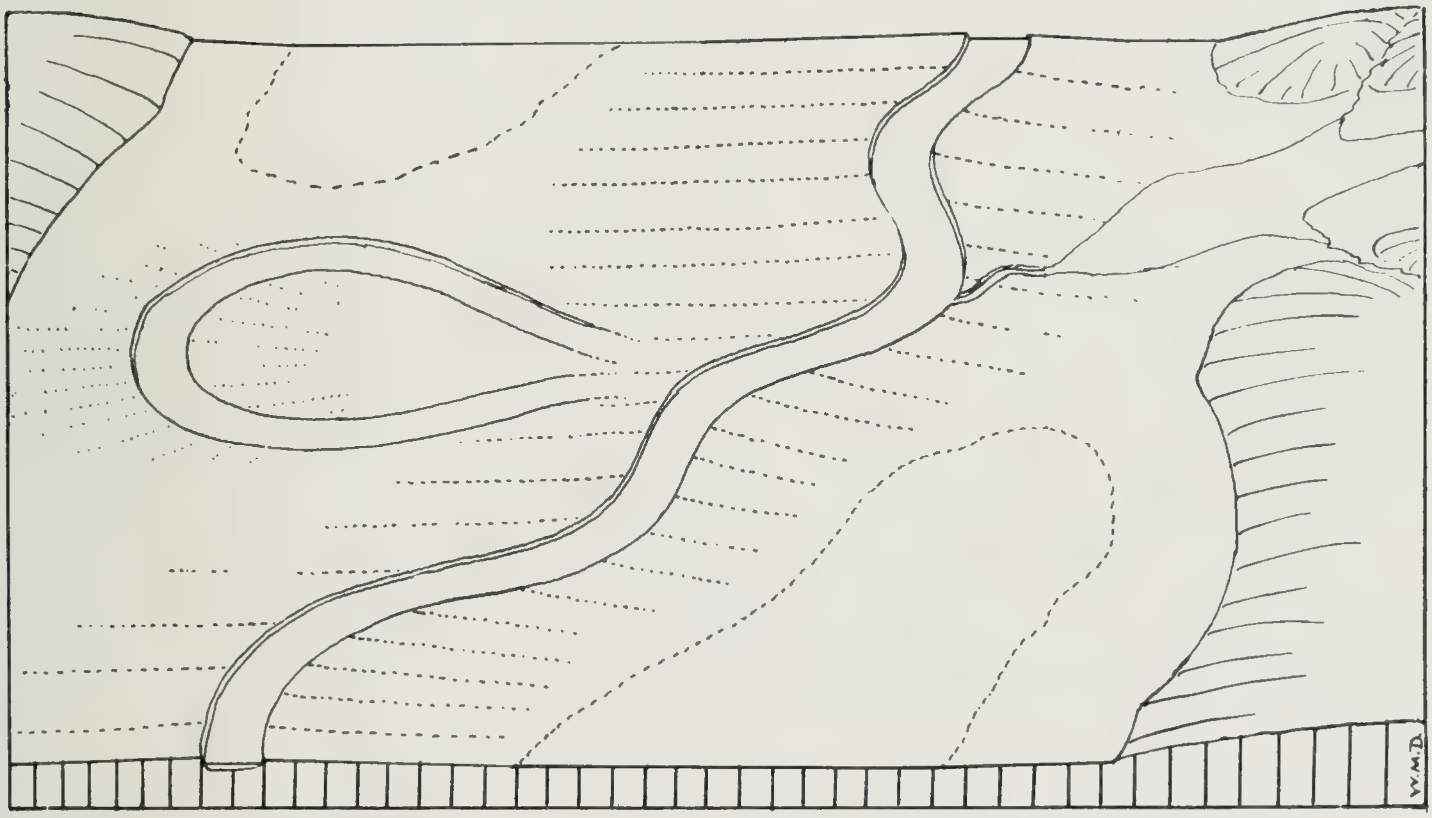


A, DIAGRAM OF A LANDSLIDE LAKE IN A MOUNTAIN VALLEY

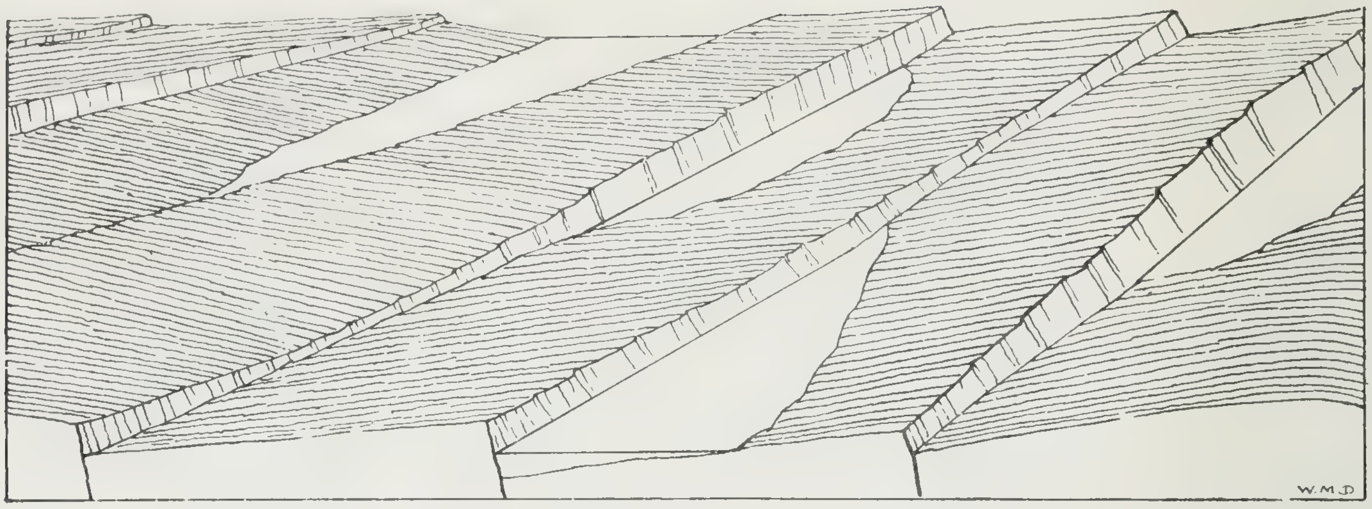


B, A LAKE IN A VALLEY-HEAD ABOVE A GROUP OF VOLCANOES

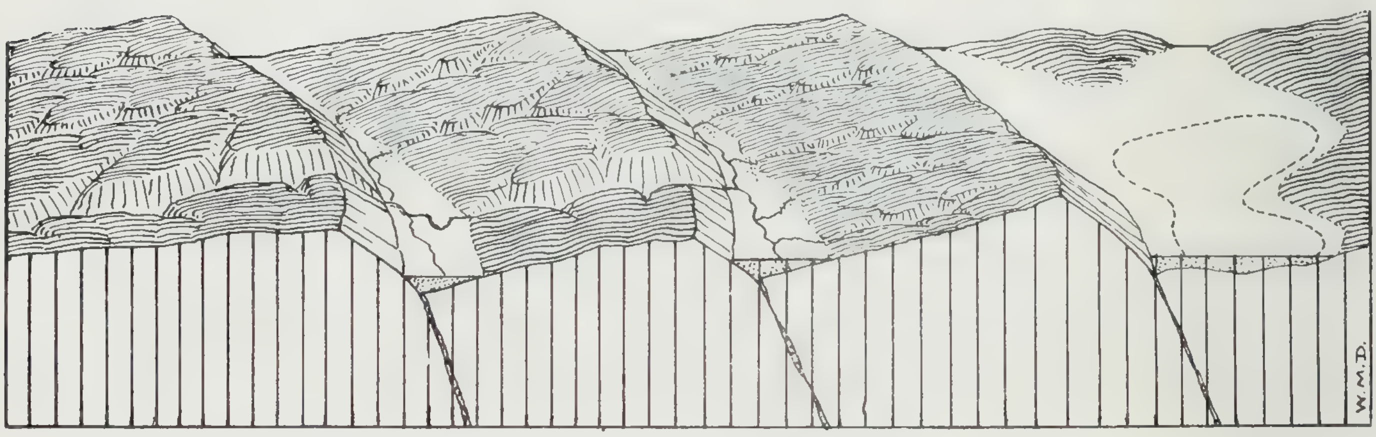
The lake outlet has cut a notch in the divide at the head of the valley.



C, DIAGRAM OF RIVER-MADE LAKES AND SLOUGHS



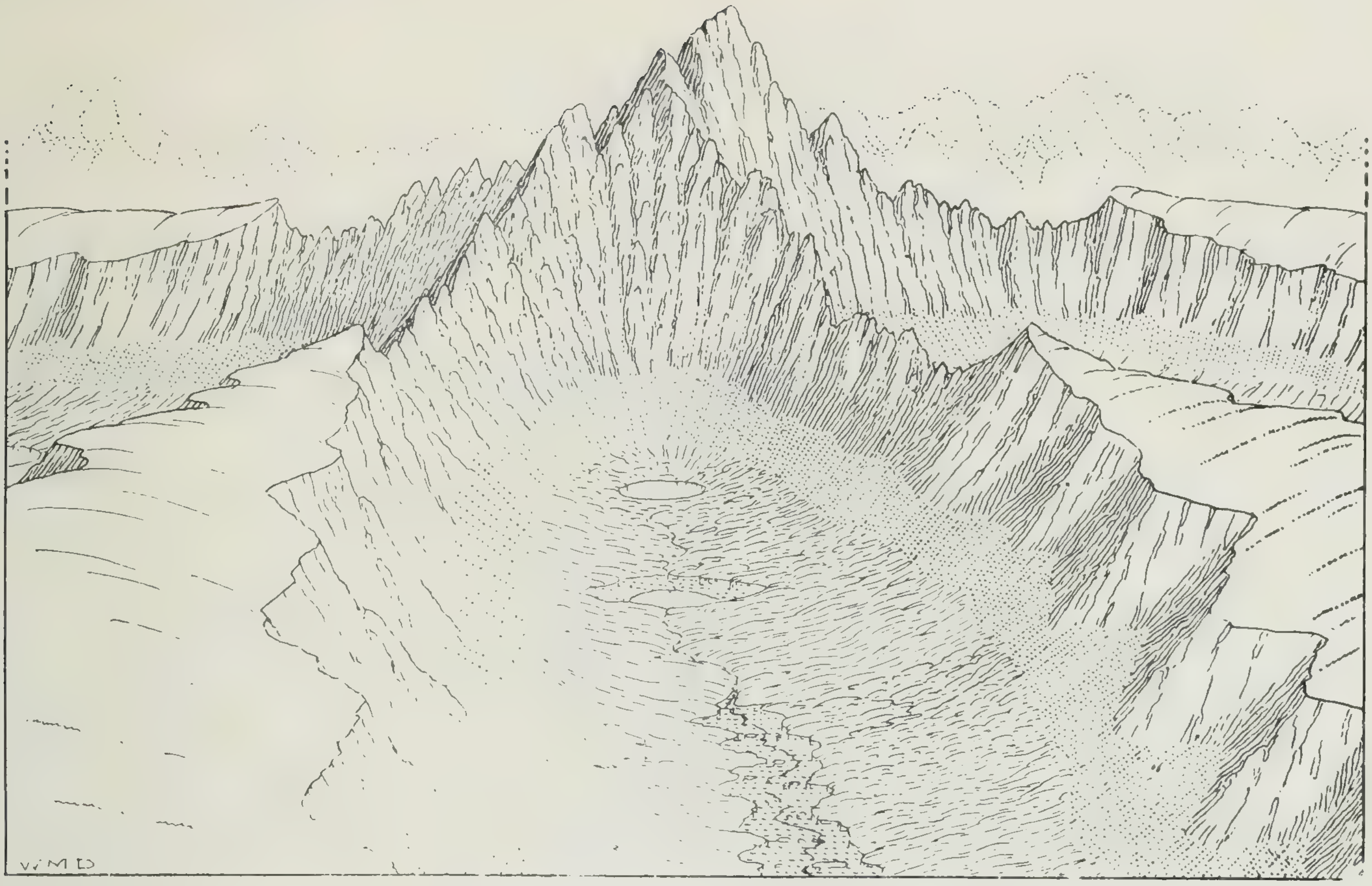
A, DIAGRAM OF DIVERSELY TILTED FAULT BLOCKS, WITH LAKES OCCUPYING THE DEPRESSIONS



B, DIAGRAM OF THE GREAT FAULT BLOCKS OF THE NORTHERN SIERRA NEVADA, WITH THE PLAIN OF HONEY LAKE ON THE EAST

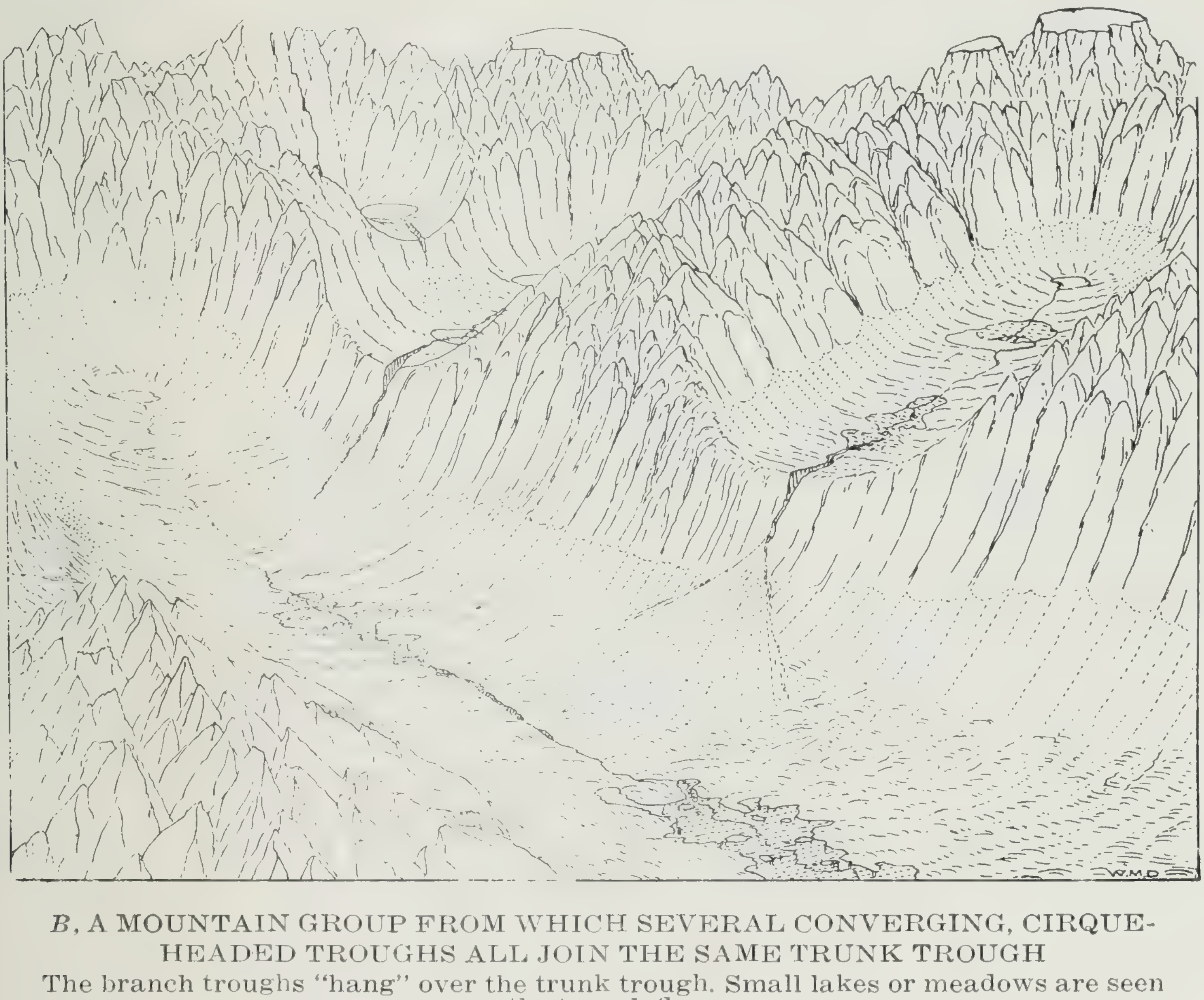
C, LANDSLIDE DIAGRAM

In foreground a recent slide with tilted trees; a small lake is held in the hollow back of it. A longer narrow slide is a short way beyond the nearer one. Three mountain-side slides are incompletely shown in the distance.



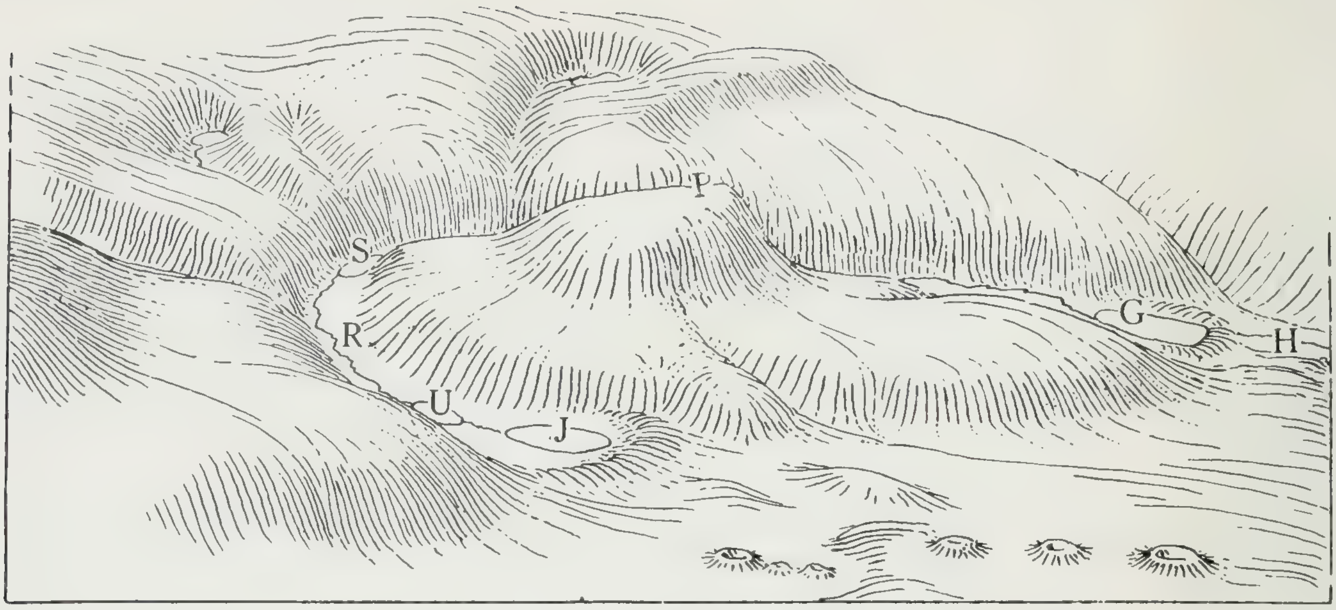
A, CIRQUE-HEADED GLACIAL TROUGHS

Radiating from a lofty peak which has been sharpened by cirque recession on all sides. Small lakes or meadows are seen on the foreground trough floor.



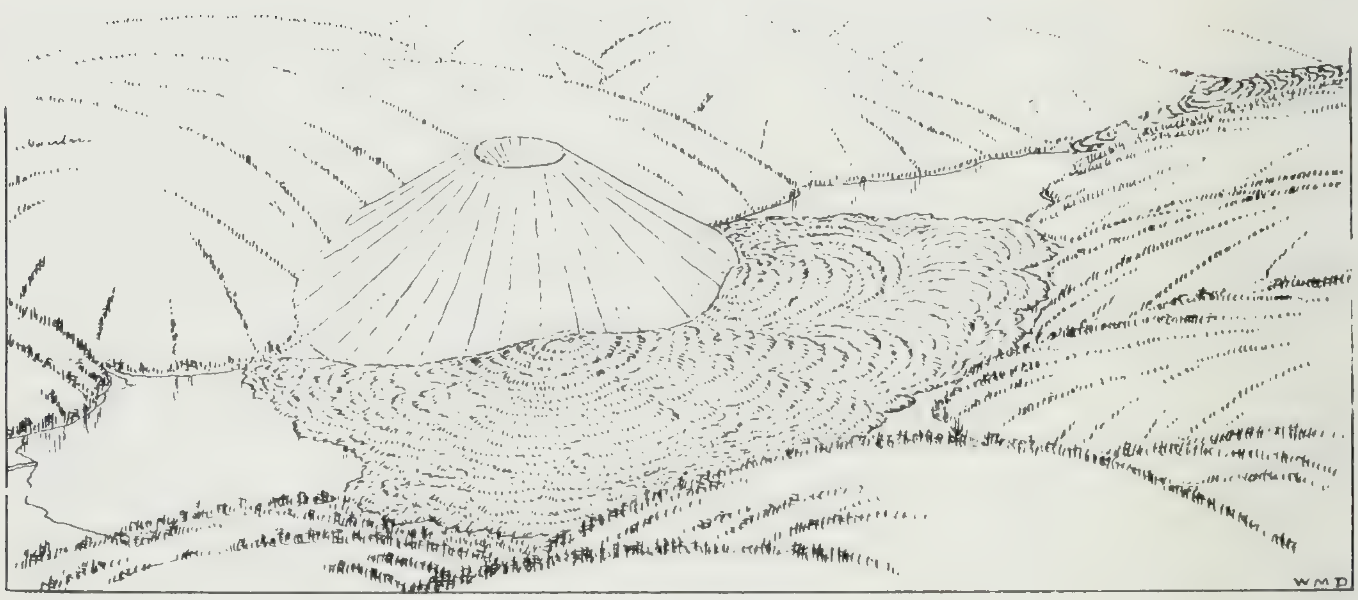
B, A MOUNTAIN GROUP FROM WHICH SEVERAL CONVERGING, CIRQUE-HEADED TROUGHS ALL JOIN THE SAME TRUNK TROUGH

The branch troughs "hang" over the trunk trough. Small lakes or meadows are seen on the trough floors.

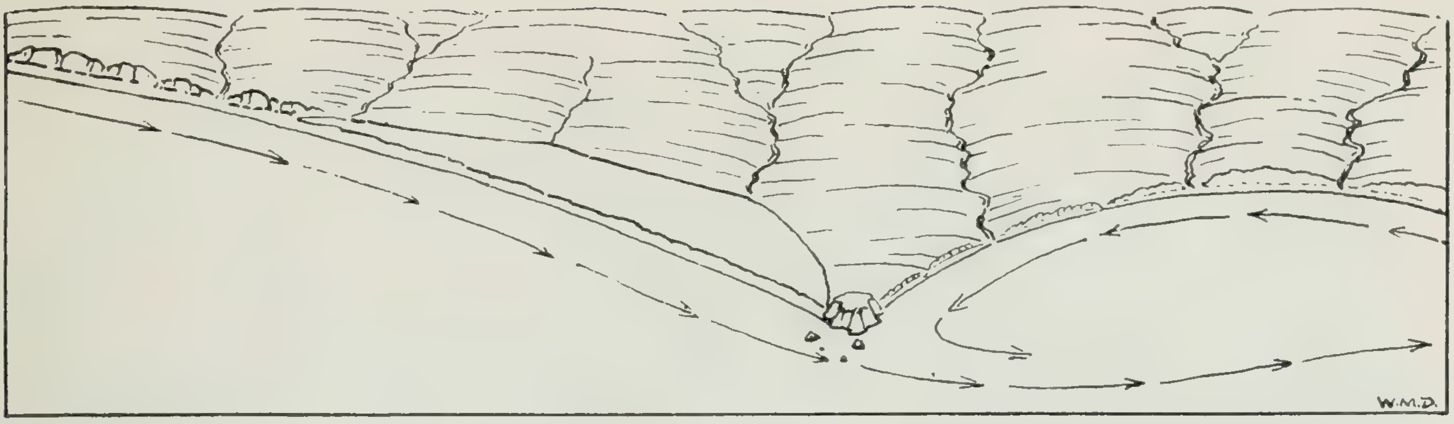


A, SKETCH OF RELIEF SOUTH OF MONO LAKE

Looking southwest; June Lake (J); Gull Lake (U); Reversed Creek (R); Silver Lake (S); Reversed Peak (P); Grant Lake (G); and Rush Creek (H).

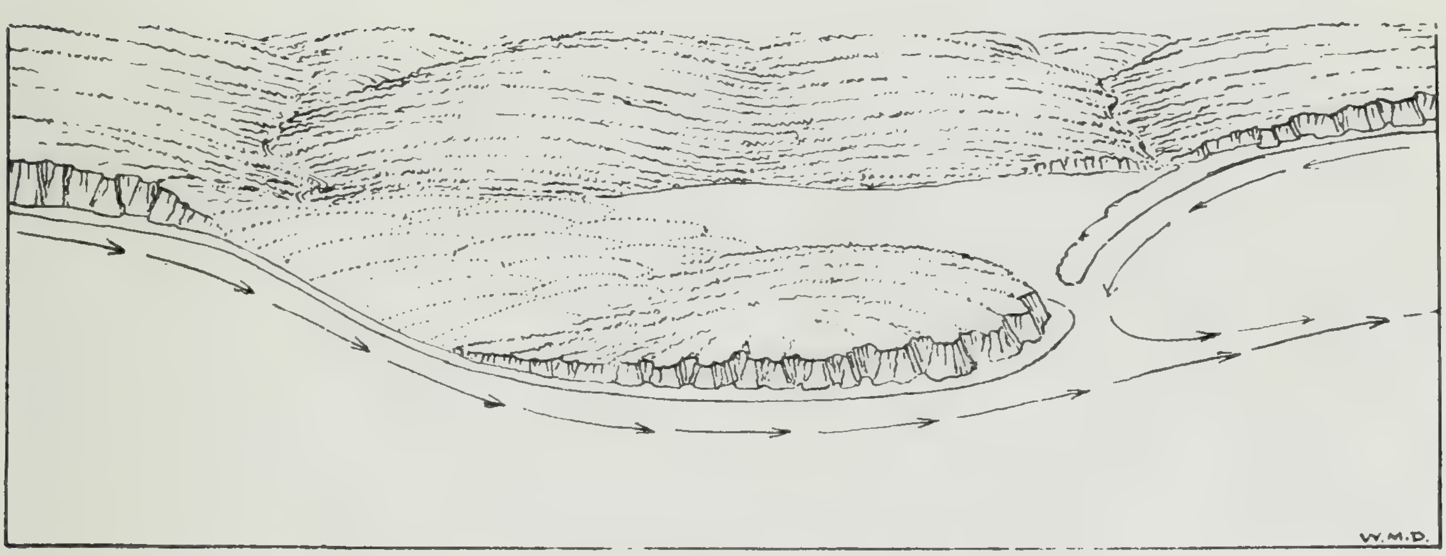


B, DIAGRAM OF VOLCANIC LAKES



A, DIAGRAM OF LAGOON ENCLOSED BY A WAVE-BUILT BEACH

B, DIAGRAM OF LAGOONS ENCLOSED BY WAVE-AND-CURRENT-BUILT BEACH ON A COAST EMBAYED BY SLIGHT SUBSIDENCE



C, DIAGRAM OF A LAND-TIED ISLAND

With a bay behind it, closed by a sand-reef beach controlled by a backset eddy current.

A, SURPRISE VALLEY
Looking northeast from crest of Warner Range.
Photo by R. J. Russell.

B, SILVER LAKE PLAYA
In the southern part of a long depression, which, farther north, is known as Death Valley.
Photo by Eliot Blackwelder.

C, FRESHWATER LAGOON
Below the Redwood Highway, north of Eureka ; looking south.
Photo by Patterson Bros., Santa Rosa.

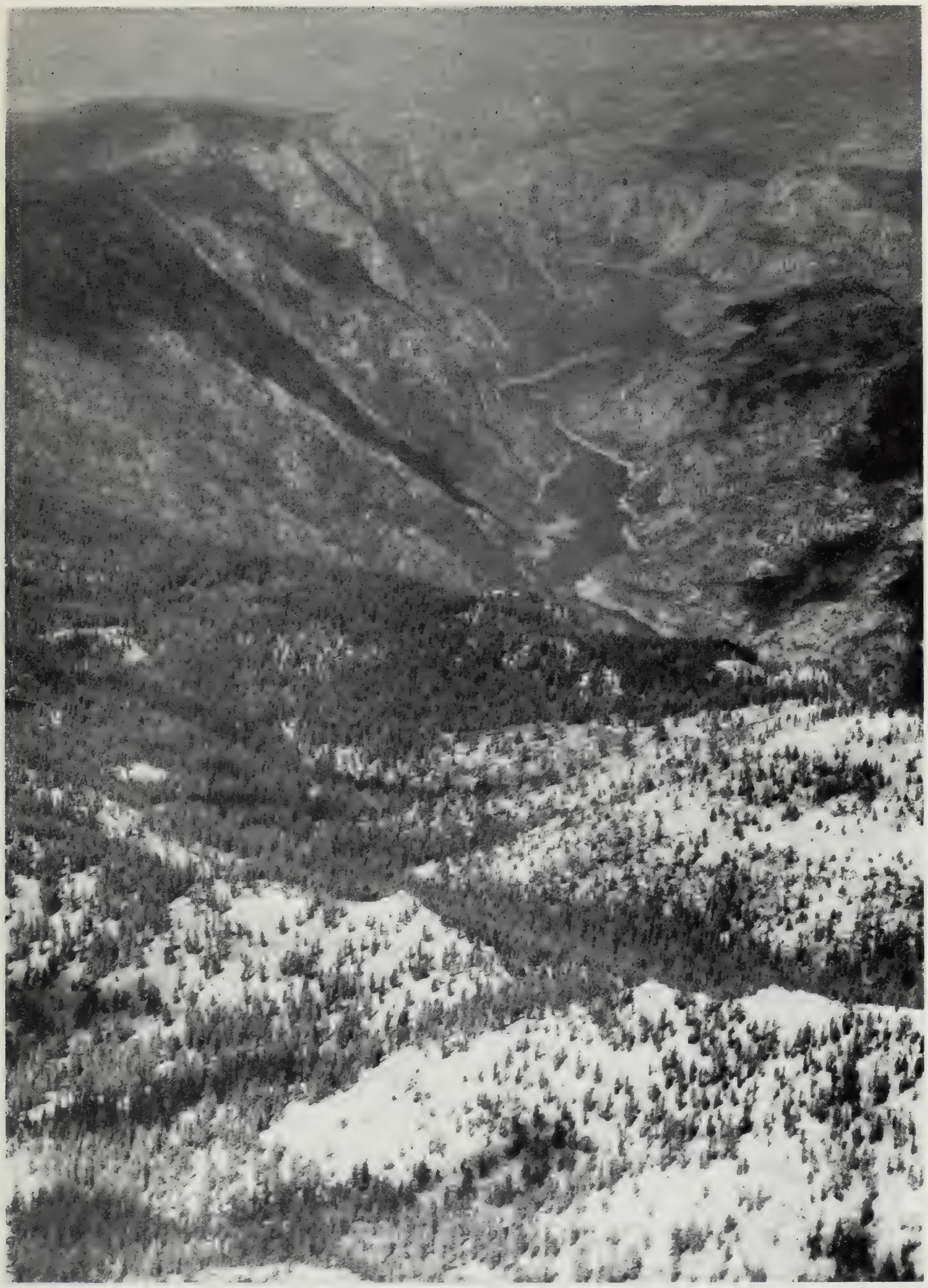
A, ISLAND LAKE
In the Siskiyou Mountains.
Photo by J. H. Maxson.

B, MARSHY MEADOW
Replacing a small glacial lake, Siskiyou Mountains.
Photo by J. H. Maxson.

THE BLUE LAKES

In the former outlet gorge of the Clear Lake basin plain. The obstructing landslide is just beyond a white field in the middle distance. The two lakes are separated by the inwashed deltas of side streams nearer the foreground.

Air-view by Erickson.



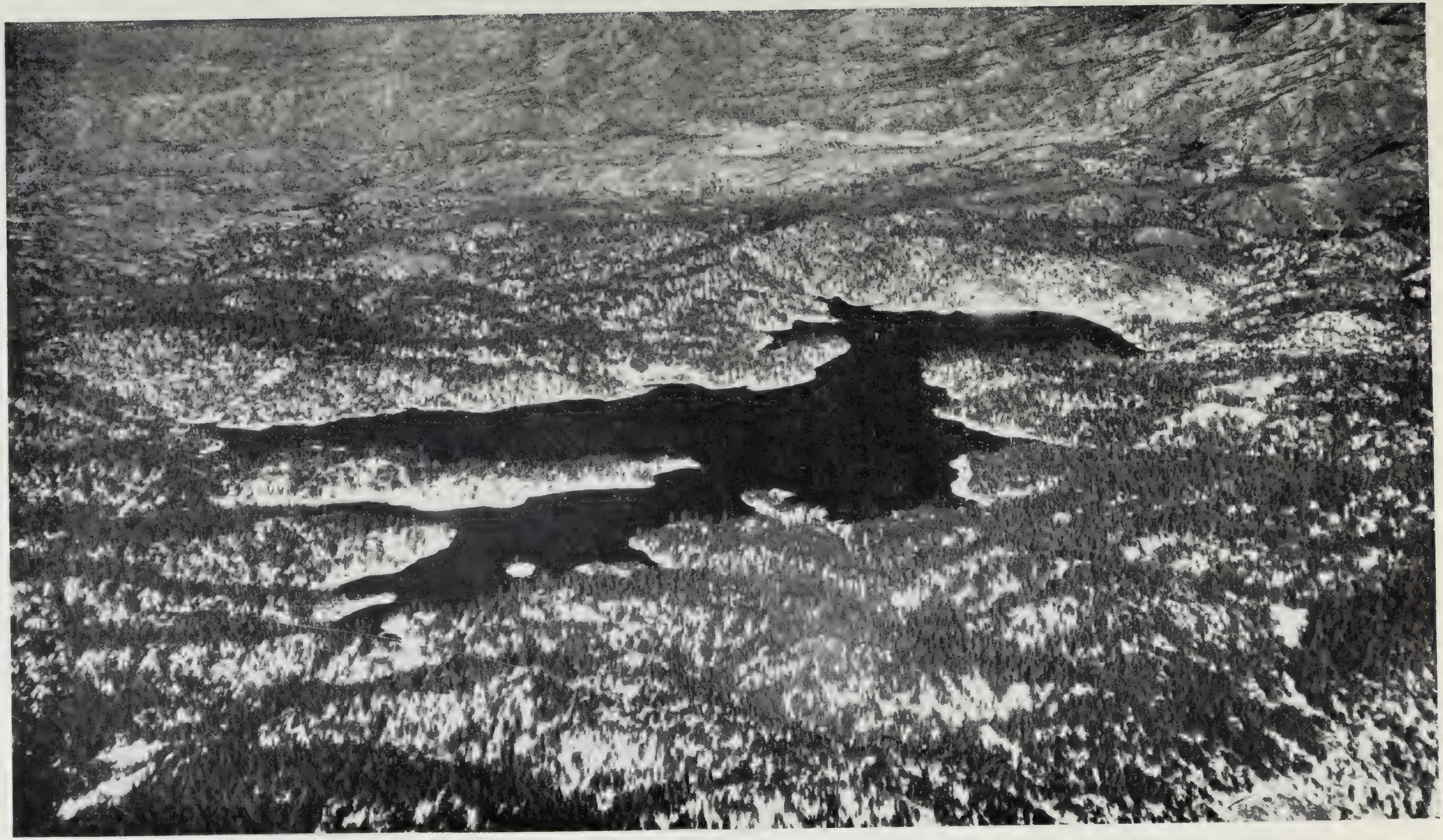
A, AIR-VIEW OF HETCH HETCHY RESERVOIR

B, THE EMBAYED MOUTH OF NOYO CREEK, MENDOCINO COUNTY
Photo by Olaf P. Jenkins.

TYPICAL GLACIAL CIRQUE AND LAKE
Rodgers Peak from the north, Sierra Nevada.
Photo by Ansel Easton Adams, courtesy of Sierra Club.

TWIN LAKES, SIERRA NEVADA
Photo by Eliot Blackwelder, courtesy of Geological Society of America, vol. 42, no. 4, fig. 10.

AIR-VIEW OF LAKE TAHOE



AIR-VIEW OF ARROWHEAD RESERVOIR

LOOKING NORTH, TOWARD THE NARROWS OF CLEAR LAKE

Air-view by G. E. Russell, San Francisco.

louette Creek, 16 miles southeast of the Yosemite Valley; also between Mammoth Mountain and Mammoth Crest, high up on the eastern slope of the Sierra, 22 miles south of Mono Lake; again, but more confusedly, farther south in the remarkable Sixty-Lake Basin at the headwaters of Kings River under Mount King, and still farther south under Mount Genevra. Garnet Lake and Thousand-Island Lakes, about 9800 feet in altitude, are exceptional among cirque lakes in being beset with rocky islets; they are drained by a roundabout stream to the Middle Fork of San Joaquin River.

Cirque lakes become less abundant and disappear in the northern and far-southern Sierra Nevada where the altitude of the range decreases. Gold Lake, 2 miles long, on a head branch of the Middle Fork of Feather River, is one of the largest in the northern mountains. Not so far north a group of cirque lakes is found under Sierra Buttes near the North Fork of Yuba River; one of them is figured by Turner.[29] Another northern group is found around Fall Creek Mountain, near the South Fork of the same river. Farther south, where the mountains gain altitude, cirque lakes are to be counted by the hundred, as may be seen on the Mount Goddard sheet of the U. S. Topographic Map at the head of San Joaquin River, the Mount Lyell sheet east of the Yosemite Valley, and the more southern Mount Whitney sheet. In the far-southern part of the range, a number of small cirque lakes occur on the headwaters of Kaweah River in the Sequoia National Forest; fourteen such lakes, more or less converted into marshes, are clustered around the headwaters of the North Fork of Stanislaus River, as shown on the Big Trees topographic map.

Irregular Lakes on Trough Floors

Lakes of this kind lie on unevenly scoured trough floors, where some parts are a little deeper than others. They are of long-oval outline when they occur in narrow, steep-walled, well-smoothed troughs, but they are of very irregular outline and are often beset with low rocky islets and knobs of round-scoured rock when they occur in broadly open, flat-floored troughs. Their depth by no means indicates the depth of trough-floor excavation beneath the floor of a preglacial valley, but only the excess of scouring of one part of the floor below another part. These irregular lake basins therefore correspond to the deeper parts of the bed of a stream channel eroded by running water. As their depth is usually small they are frequently replaced by inwashed stream detritus and thus converted into nearly level meadows (pl. 28).

Apparent examples are seen in the irregular Silver, Loon and Pleasant Lakes, in branch troughs of the South Fork of American River. It may be here noted that, although glacially enlarged valley-troughs are commonly described as U-shaped in cross profile, they are, as a rule, much more like well opened, round-bottom Vs. It is only by way of exception, and in the Sierra Nevada only in the terminal troughs of Tahoe glaciation, that the U-shape is closely approached, as is shown by the rarity of cliff-walled valleys of the Yosemite type, among which Matthes has shown that Kings River, Hetch Hetchy, and Tehipite troughs are to be included with the Yosemite masterpiece.[30]

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[29] Turner, H. W., U. S. Geol. Survey Geol. Atlas, Downieville folio (no. 37), fig. 3, 1897.

[30] Matthes, F. E., op. cit.

Lakes on Ice-Scoured Sierran Highlands

The irregularly scattered lakes of the broad Sierran highlands lie in small and shallow rock basins. Where the country rock is granite, they are formed amid smoothly scoured and severely barren undulations of the surface; but on weaker rocks, where forests alternate with grassy glades, they are associated with a more pleasingly picturesque scenery. One should here, in order to appreciate the transformation of the landscape that ice-scouring has accomplished in the glaciated areas, recall what was said above as to the absence of highland lakes in preglacial time, and to that may be added Lawson's description of a non-glaciated southern area of the mountains. That experienced observer wrote: "A remarkable feature of the upland surfaces is the prevailing absence of water courses or incisions of any kind due to stream cutting. * * * The surface is everywhere encumbered by blocks of granite, formed by the intersection of joints and dislodged by the heaving action of frost. The veneer of loose blocks is so thick that the waters from summer rains and from melting snows do not gather in runways and so establish lines of stream cutting, but flow in a diffused fashion between and beneath the blocks. * * * It is only when we get to the bottom of the canyons and cirques that the granite is tight enough to hold water on its surface. It would thus appear that these upland surfaces are as free from the attack of running water as are the driest deserts."[31]

It may be said further that the highland veneer of granite blocks has probably been continued from an early time before the upheaval of the mountain mass, when it was part of an extensive and soil-covered lowland of long-continued degradation, which in its southern area at least probably had a desert climate; for on such a lowland the well disintegrated soil at the surface must have been underlaid by less disintegrated joint blocks to a certain depth below the surface. Not that all the joint blocks on the non-glaciated highlands of today were then prepared, but that the present blocks there are the direct successors of their ancient predecessors. A veneer of similar blocks probably overspread all the highlands in preglacial times, but in the areas that became glaciated they were swept away down to firm rock, as the following quotations show.

Lindgren has described the more barren highlands as "vast stretches of dazzling white granitic rock surface, worn and rounded"; and he adds concerning a climax area: "There are few more imposing sights than the ice-swept rock deserts of the * * * Devil's Basin,"[32] a wide area at an altitude of 8200 feet, dotted with little lakes or with grassy flats at the head of the South Fork of American River, 7 miles southwest of Lake Tahoe. Humphrey Basin is a similar area, over 11,000 feet in altitude, at the head of the South Fork of San Joaquin River; it is included on the Mount Goddard map sheet, which shows the well-named Desolation Lake, a mile in length. The depth of these highland lakes is not a true measure of glacial erosion that the highlands have suffered; it measures only the excess of erosion in the lake basin below that on the neighboring surface.

Blackwelder remarks that the ancient glaciers left on the scoured highlands "vast areas of comparatively bare granite, upon which so little

[31] Lawson, A. C., op. cit., pp. 313, 314.

[32] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Pyramid Peak folio (no. 31), 1896.

forest grows that the rocks stand out gray and white."[33] The monotony of these rock deserts is here and there relieved by tree-covered patches of glacial detritus; also by perched boulders, left there when the ice cover melted away. The undulating and polished granite surface, more or less scaled off, and the perched boulders are well illustrated in Matthes' report (pls. 35B, 36, 37B), referred to above.

The lakes on the scoured highlands are not infrequently rimmed with low walls or "ramparts" of boulders and stones, which have been, according to Gilbert,[34] gradually pushed out from the shallow bottom in the milder spells of winter weather, when the ice expands a little after having contracted during preceding spells of severe cold. When its temperature falls 7° Fahrenheit, the ice of a frozen lake a mile across will contract a foot. Cracks are then opened through the ice; but they are soon closed by new-formed ice. A warm spell then expands the ice and it spreads a little on the shores. A repetition of this through many winters has resulted in shoving outward all boulders that the shore ice rests upon, and thus in time a rampart is formed.

Trough-End Lakes

Lakes lying at the end of an over-deepened valley-trough of the Tioga epoch, where their retention is aided by a loop of morainic ridges, are nearly always of simple, long-oval outline and of a considerable depth, some being as deep as 200 or 300 feet; but their original length is somewhat decreased by the inwashed delta of the trough stream. Thus Merced Lake, in a trough-end basin of the Tioga epoch drained by Merced River to the Yosemite Valley, is now partly filled by a forested delta, well shown in plate 12B of Matthes' report. Blackwelder notes that near these lakes, "acres of polished and grooved rock are a familiar sight"; also that the rock polish is here better preserved than on similar surfaces scoured by the earlier Tahoe glaciers.

The oftenest seen lake of this important class is Donner Lake, which lies next north of and well below the line of the Southern Pacific Railroad where it descends the eastern slope of the Sierra Nevada from Donner Pass to Truckee Valley. It is 3 miles long and is enclosed by heavy morainic ridges, in great part of Tahoe age, at an altitude of 6095 feet. Another terminal lake in the same drainage basin, but less often seen, as it lies higher in the mountains to the northwest, is Independence, about 2 miles long at an altitude of nearly 7000 feet. The southern or main upper course of Truckee River, which drains Lake Tahoe, leads to several well known terminal lakes: Fallen Leaf Lake is a popular summer resort on the southwest side of Lake Tahoe; it is of about the same length as Donner, but has an altitude of nearly 6400 feet. The Tioga terminal moraine, close around the foot of the lake, is of small size; the Tahoe moraines, enclosing the Tioga moraine, are vastly larger; one on the southeast of the lake is over 3 miles long and rises 900 feet like a great railroad embankment. The glacial origin of this beautiful lake was recognized by Le Conte 60 years ago; but in stating that the

[33] Blackwelder, Eliot, Pleistocene glaciation in the Sierra Nevada: Geol. Soc. America Bull., vol. 42, pp. 865-922, 1931. This paper contains several excellent views: Fig. 1, a lateral glacial trough hanging high over a main trough; Fig. 2, talus in a glacial trough; Fig. 3, glacially polished granite with perched boulders; Fig. 10, a divided trough lake, here reproduced in Fig. 17; Fig. 15, a meadow replacing a glacial lake.

[34] Gilbert, G. K., Lake ramparts: Sierra Club Bull., vol. 6, pp. 225-234, 1908.

basin of Lake Tahoe also had been filled by ice he showed an exaggerated idea of the dimensions of the ancient glaciers.[35]

A recent and well illustrated essay by Jones on this picturesque district limits the glaciers to more moderate lengths.[36] Cascade Lake, 3 miles northwest of Fallen Leaf and of similar size and altitude, is pictured as seen from above in a compound loop of morainic ridges. A mile farther north is Emerald Bay, like the other two lakes except that it lies at the level of Tahoe, with which it is connected through a frontal opening in its 600-foot moraines. Echo Lake, a mile long, 3 miles south of Fallen Leaf, belongs in a somewhat different class, as it lies at an altitude of 7500 feet just back of the lip of its lateral trough, which hangs 500 feet above the floor of the main and much larger trough of the Upper Truckee glacier. This lake is peculiar in having its waters artifically diverted from Truckee River and led southward through a tunnel to a head branch of the South Fork of the west-flowing American River, to increase the volume of that Fork for electric power. Other examples of trough-end lakes are Emigrant, Huckleberry and Tilden, each about 2 miles long and all in steep-sided branch troughs of the north branch of Tuolumne River.

A peculiar group of glacial lakes, well illustrated on the topographic map of Yosemite National Park, 1932, is found in the semicircular glacial trough which is drained by the well-named Reversed Creek back of Reversed Peak, about 12 miles south of Mono Lake. The creek heads in June Lake, which is apparently held by a terminal moraine at the northern end of the eastern arm of the semicircle; it then flows south through Gull Lake and, curving to the west, enters Silver Lake, from which it flows north along the western arm of the semicircle and thus, a few miles farther north, reaches Grant Lake, held by another terminal moraine, through a gap in which the outlet, there known as Rush Creek, continues to Mono Lake, about 7 miles distant.

Twin Lakes, 3 miles in combined length, stand at altitudes of 7076 and 7096 feet on a fork of Walker River, 15 miles southwest of Mono Lake. They result from the subdivision of a single, trough-end lake by inwashed detrital fans near its mid-length, as explained and illustrated by Blackwelder (pl. 36). These lakes are shown with many others on the Bridgeport topographic map. The most famous double lake of this kind is in Switzerland, where an originally single lake, occupying the long and greatly overdeepened valley trough of the River Aar, has been divided into Lakes Brienz and Thun by the combined deltas of two opposite side-streams; the beautiful town of Interlaken stands on the fans; and the outlet of Lake Brienz winds between the fans to Lake Thun.

A group of tarns, known as the Volcanic Lakes, occupy the floor of the large, cirque-like trough head of Dougherty Creek, a south branch of the Middle Fork of Kings River; they are believed to be not of volcanic but of glacial origin and are said to have taken their name from some volcanic rock near by.

Extinct Glacial Lakes in the Sierra Nevada

It has been noted above that the trough-floor and terminal lakes of the long Tahoe glacial troughs are now as a whole converted into treeless meadows or forested valley floors of inwashed detritus, the meadows being

[35] Le Conte, Joseph, On some ancient glaciers of the Sierra: Am. Jour. Sci., 3d ser., vol. 10, pp. 126-139, 1875.

[36] Jones, Wellington, Glacial land forms in the Sierra Nevada south of Lake Tahoe: Univ. California, Pub. Geog., vol. 3, pp. 135-157, 1929.

attractive features of the Sierran highlands. Such meadows and plains are longer than the lakes which they replace, because their gently slanting surface extends farther up the valley-trough floor than the level surface of the lake could reach.

The best known example of this kind occupies the great cliff-walled glacial trough of the Yosemite Valley, of which Matthes has given an admirable description, above cited. The lake which originally filled the gouged-out terminal rock basin of the trough and which was partly held back by the terminal moraine of its 20-mile Tahoe glacier, is estimated to have had a length of 5½ miles, and it was therefore one of the largest of its class. There is little question that the marvelous scenery of the Valley would be more marvelous still if the lake had not been destroyed. Another detrital plain occupies the lower part of Tenaya Canyon, the eastward extension of the Yosemite. Mirror Lake (see Matthes' plate 47a), a small pool on that plain, is not a remnant of the rock-basin lake that the plain replaces, for that lake has been completely filled; the little lake is due, again according to Matthes, to the active, avalanche-like downfall of rock blocks from the oversteepened cliffs, by which the stream that formed the plain has recently been slightly obstructed. One of the longest aggraded troughs in the Sierras is found in the Tuolumne Meadows; it probably conceals several trough-floor rock-basins.

Non-Sierran Glacial Lakes

The only glacial lakes in the mountains of southern California are two small ones, Dollar and Dry, in cirques below Mount San Gorgonio, the dominating dome-like summit, 11,485 feet in altitude, of the San Bernardino Mountains.[37] The mountains in the northern part of the state contain a considerable number of glacial lakes, all of small size. Curiously enough, Lassen Volcanic National Park, between the Sierra Nevada and Mount Shasta, contains according to Williams[38] many more glacial than volcanic lakes. The park district pretty surely possessed a good number of lava-barred lakes during a former time of greater volcanic activity; but the lakes then produced have been converted into plains and some of the lakes found there today appear to result from the excavation of these filled basins by ice action. To the south and east of Lassen Peak, Helen, Emerald, Shadow and Cliff lakes, each only a quarter-mile or less in diameter, occupy basins wholly the product of glacial erosion. Farther east Rainbow, Twin, Swan, and the six Cluster lakes have been similarly produced. The same may be said of a score of little wet-weather ponds on the lava flow of Crater Butte, east of the park center. Horseshoe Lake, nearly a mile across, and Juniper Lake, about 1 by 2 miles, in the southeastern part of the park, occupy intervolcanic depressions modified by glacial action.

Farther northwest, a good number of small cirque lakes occur in the Klamath Mountains at altitudes of from 6500 to 7500 feet.[39] A small lake of this kind in the neighboring Siskiyou Mountains is shown in plate 32*A* and a small meadow-marsh resulting from the filling of such a lake is shown in plate 32*B*.

[37] Fairbanks, H. W., and Carey, E. P., Glaciation in the San Bernardino Mountains, California: Science, vol. 31, pp. 32-33, 1910.

[38] Williams, Howel, Geology of the Lassen Volcanic National Park, California: Univ. California, Dept. Geol. Sci. Bull., vol. 21, pp. 191-385, 1932.

[39] Hershey, O. H., Ancient alpine glaciers of the Sierra Costa Mountains in California: Jour. Geology, vol. 8, pp. 42-57, 1900. See the Sawyers Bar and Seiad sheets of the U. S. Topographic Map.

Lakes in Basins of Limestone Solution

Limestone is a relatively soluble rock: some of its underground fractures or "joints" are commonly more or less enlarged into passages or caverns by the solution of their walls in ground-water. Such enlargement commonly begins along the intersection of two joints; and as it progresses surface streams frequently disappear by descending at "sinks" into the underground passages. If such an underground passage is obstructed, a pond or lake may be formed over the sink. It has been suggested by Baker [40] that Bear Lake, which had a length of about a mile in a flat-floored valley at an altitude of about 6700 feet in the San Bernardino Range, is of this origin. A dam at the lake outlet now holds back a reservoir 5 miles long when filled to capacity.

In certain limestone districts lakes are formed by the obstruction of rivers where calcareous tufa is deposited in river channels, apparently where springs charged with limestones in solution emerge from the channel bed. No lakes of this kind have been reported in California.

Lakes of Volcanic Origin

Several lakes of volcanic origin occur in Lassen Volcanic National Park in the northern part of the state, but the lakes there are mostly of glacial origin, as already told. They are all well shown on the topographic map of the park (1929). Two of the best known are Butte (formerly Bidwell) and Snag Lakes, each about a mile long and at an altitude of about 6500 feet: they were first described by Diller,[41] but the following details are taken from a later and fuller account by Williams.[42] He explains that the valley of a north-flowing stream was obstructed by a lava flow in preglacial time (pl. 29*B*), and a lake several miles in length was formed upstream from the obstruction. The basin was, however, much modified by a glacier which for a time crept along the valley floor, although it did not succeed in wholly removing the lava barrier. After the glacier disappeared a lake occupying the modified basin was more or less filled with marshy deposits. Then a small volcano, known as Cinder Cone, was built up on the western side of the valley and a ragged lava stream that was extruded from its base spread over a medial part of the original lake basin (pl. 29*B*), thus producing Snag Lake.

The small Hat Lake, at the northeast base of Lassen Peak, is the youngest lake in the park, as it was formed in consequence of the obstruction of the headwaters of Hat Creek by a mudflow from the peak during the eruption of 1915.

Lakes not infrequently occur in the craters of recently extinct volcanoes. Thus a small lake occupies the summit cavity of Crater Butte, east of Lassen Peak. A little wet-weather lake of the same kind occupies the crater of an unnamed cone about 20 miles farther east; a tiny lake is mapped at an altitude of 12,000 feet in the crater of Shastina, a secondary volcano on the west slope of Shasta; and two minute lakes are found in the craters of small cones on Paoha Island in Mono Lake.[43]

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[40] Baker, C. L., Mohave Desert region in southern California: Univ. California, Dept. Geol. Sci. Bull., vol. 6, pp. 333-383, 1911. See p. 364, pls. 41, A and B.

[41] Diller, J. S., A late volcanic eruption in northern California: U. S. Geol. Survey Bull. 79, 1891.

[42] Williams, Howel, op. cit.

[43] Russell, I. C., Quaternary history of Mono Valley, California: U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 261-394, 1889. See p. 373.

Medicine Lake in northeastern California stands near the center of the Modoc lava field which has been mentioned above in the account of several fault-basin lakes at the northern boundary of the state; and this lake like those has been described by Peacock,[44] in brief as follows: A broad and low dome of lava was built up by local eruptions of fluid lavas on the larger field; and the dome was crowned by an imperfect ring of later cones, of which Mount Hoffman is one, most of them made of cinders; their brown or reddish color is more or less concealed by a forest cover. The highest member of the ring, Big Glass Mountain, about 8000 feet in altitude, composed of dark obsidian or volcanic glass, which appears to have been viscous when erupted and which therefore accumulated in a huge pile instead of spreading out in nearly level flows. The ring includes also several smaller cones of pumice or frothy lava, white and barren. Some of these eruptions are of extremely recent date; one of the lava flows, when just at the limit of its advance, pushed and charred a tree trunk that is still standing at the lava edge. Within the ring of cones a hollow space remains less filled up, and in its lowest part lies Medicine Lake, about 2 miles long at an altitude of 6500 feet. It is clear and fresh although it has no overflowing outlet.

Similar to but much smaller than Medicine Lake is Thurston Lake, which occupies a deep hollow that is accidentally enclosed by the up-building of several volcanic mounts around it in the volcanic district which adjoins Clear Lake, above described, on the south. The water surface in these two lakes is said to stand at the same level and to vary equally with change of seasons, as if a connection between the lakes were maintained by underground percolation. Several similar hollows among these volcanic mounts are now occupied by detrital plains.

Ancient Volcanic Lakes

A number of lava-barred lakes of earlier origin in the Lassen Peak region have been converted into meadows. For example, about 20 miles southeast of the peak, an ancient lava flow ran into and formed a dam across the valley of the North Fork of Feather River, and the river thereupon rose in a lake; but what with inwash of detritus and erosion of an outlet gorge through the dam, the lake has disappeared. Its bed is known as Big Meadows, 15 miles in length,[45] now in part flooded in a reservoir as told below. Similar features are found around Mount Shasta; the largest plain, known as Shasta Meadows and measuring 20 by 10 miles, lies 20 miles northwest of the great volcano at an altitude of 2750 feet. It is probable that several similar meadow plains would be found near Lassen Peak, were it not that their unconsolidated detritus has been removed by glacial scouring. Juniper and Horseshoe Lakes, already described in the section on lakes of glacial origin as occupying inter-volcanic depressions modified by glacial erosion, deserve mention here also, because in preglacial time they were probably represented by detrital plains.

In his account of Mono Lake, I. C. Russell made brief mention of a former lava-barred lake, now represented by a small playa basin; it lies about 30 miles northeast of Mono. A well defined but extinct lake of the same origin in Truckee Valley is now, according to Lindgren,[46] repre-

[44] Peacock, M. A., The Modoc lava field, northern California: Geog. Rev., vol. 21, pp. 259-275, 1931.

[45] This ancient lake is mapped in Plate 47 of J. S. Diller's report on the Geology of the Lassen Peak district: U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 395-432, 1889.

[46] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Truckee folio (no. 39), 1897.

sented by Martis Valley, a plain of fine sediments 4 miles across at an altitude of 5900 feet, next east of the town of Truckee. The lake rose to an altitude of 6000 feet in consequence of a lava barrier that blocked Truckee River not far to the east. The river has now not only washed a quantity of sediment into the basin but has drained away the lake by cutting down a gorge through the barrier; since then it has trenched a shallow valley along the northern border of the lake-basin plain.

A larger example of a plain that replaces a volcanic lake occupies Mohawk Valley in the northern Sierra Nevada. The original depression is believed to have been a down-faulted trough, drained westward by the Middle Fork of Feather River, and therefore resembling the two similar fault-troughs farther northeast, drained by the North Fork, as above described under fault-basin lakes. According to Turner [47] the Mohawk trough was blocked on the northwest by a heavy body of lava; the lake thereupon rose to a level of 5100 feet, thus gaining a length of 11 miles and a width of 2 or 3, with a northeast arm 7 miles long. Although now drained by a gorge cut through the lava barrier, the lake-shore terraces, more or less dissected by local brooks and the bottom deposits at levels of from 4400 to 4600 feet memorialize the vanished lake. Not far south is the larger intermont basin plain of Sierra Valley of similar origin; it will be described in the next section with Lake Tahoe.

Two small examples of extinct, lava-barred lakes are known near the above-described Clear Lake of the northern Coast Ranges. One lies between the two eastern arms of the lake in a mountain cove, the eastward opening of which has been blocked by a small lava sheet. The resulting basin, measuring a mile or more in length, is mostly occupied by a plain, but its western part is overspread after winter rains by the shallow Borax Lake, which vanishes in summer leaving a barren, white flat. A larger basin plain, measuring 1 by 4 miles, lies in an upland valley north of the lake arms; the valley outlet is reported to be blocked by a lava flow: this secluded plain presents an attractive, park-like appearance by reason of the scattered oaks that flourish on its level fields.

An extinct lake in the southern Sierra Nevada, now represented by several miles of meadows at an altitude of 8200 feet, is drained by Golden Trout Creek, which cascades down a gorge that it has cut in an obstructing lava flow in its westward descent to the canyon of the Upper Kern River. The lava flow came from a near-by cone of small size.[48]

Hot-Spring Lakes

In striking contrast to an above-described lake, the basin of which results from the solution of limestone rock in descending surface waters, are certain small lakes of Lassen Volcanic National Park. They result from the solvent action of ascending hot-spring waters which, coming from an underground source where high volcanic temperatures still prevail, rise through the lavas of extinct volcanoes, disintegrate them, carry away their more soluble minerals, and leave an insoluble residue of sticky kaolin mud on the shallow floor of the resulting cavity.

The largest and best known of these is the famous Boiling Springs Lake—Lake Tartarus of the earlier maps—which is situated at an elevation of 5750 feet in a cavity on the northeast slope of Red Mountain, near the middle of the southern border of the park. According to Day

[47] Turner, H. W., U. S. Geol. Survey Geol. Atlas, Downieville folio (no. 37), 1897.

[48] Lawson, A. C., The geomorphogeny of the upper Kern basin: Univ. California, Dept. Geol. Sci. Bull., vol. 3, pp. 291-376, 1904. See p. 320, pls. 31, 35, 36.

and Allen,[49] it is 220 yards across when filled to overflowing. Its shore is then marked by a chain of steaming springs and bubbling mud-pots. At times of lower water, it is more quiet. The group of hot-spring pools known as Bumpus Hell of similar origin, at an altitude of 8000 feet in a crater-shaped cavity 500 by 1400 feet across, 2 miles south of Lassen Peak, is remarkable for its boiling fountains and sulphurous odors. The steam issuing from one of its roaring fumaroles had a temperature of 250° centigrade in 1916. The temperature of its pools was 86° centigrade, which is the boiling point of water at that altitude.

The water of hot volcanic springs is explained by some geologists as wholly derived from the steam liberated from molten rock or ''magma,'' during its ascent from deep subterranean sources; it is therefore called ''juvenile'' water, because it is believed never to have reached the earth's surface before. Detailed analyses of the Lassen Peak hot springs have led the above-named authors to reject this view; they regard the water of those springs as chiefly supplied, like ordinary springs, by local rainfall, and explain its high temperature by the addition of a relatively small amount of steam released from underground magmas.

Lake Tahoe and Sierra Valley

Lake Tahoe, the most famous of California lakes, but partly included in the western angle of Nevada, deserves a section for itself (pl. 37). It measures 21 by 12 miles, stands at an altitude of 6225 feet, and has the altogether exceptional depth of 1645 feet. Its origin is composite, as explained by Lindgren[50] and Reid.[51] It is held by a volcanic barrier in the southern part of a great, down-faulted trough, 70 or 80 miles in length, northwest-southeast, which in association with the faults of the more northern part of the Sierra Nevada described by Diller, as told above, separates some outstanding mountain blocks from the main mass of the Sierra Nevada along the northern third of its eastern border. A main scarp of the range, which here forms the western side of the Tahoe basin, may be traced more or less continuously for 120 miles northwestward. Tahoe is thus related to lakes in little filled intermont troughs, as well as to volcanic lakes.

The barrier which shuts off the basin of Tahoe from the rest of its long trough is a somewhat ancient and much dissected volcano, known as Mount Pluto, 8700 feet in summit altitude. Lindgren explains that when this great barrier was first formed, the lake rose several hundred feet higher than now. Its outlet, Truckee River, then ran northward between the western slope of the volcano and the main eastern scarp of the Sierra Nevada. The lake level was slowly lowered as the outlet cut a gorge through the lava barrier. A second rise of lake level was caused by a later lava flow which blocked the first-cut gorge, thus making the lake doubly of volcanic origin; then a second gorge was eroded and the lake was again lowered. According to Blackwelder,[52] glaciers from the west entered Truckee Canyon and built large moraines in it as much as 200 feet above the present lake level; thus obstructing the outlet for a third time and

[49] Day, A. T., and Allen, E. T., The volcanic activity and hot springs of Lassen Peak: Carnegie Inst. Washington Pub. 360, 1925. See pls. 8, 9; fig. 44.

[50] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, 1911. See pl. 1.

[51] Reid, J. A., The geomorphogeny of the Sierra Nevada northeast of Lake Tahoe: Univ. California, Dept. Geol. Sci. Bull., vol. 6, pp. 89-161, 1911.

[52] Personal letter, dated July 6, 1932.

making it partly of glacial origin. Fallen Leaf and other lakes, held back by moraines on the southwestern side of Tahoe, have been mentioned above.

Lake Tahoe is probably best known outside of California from having been mentioned in *Roughing It* by the American humorist, Mark Twain, who wrote amusingly of the transparency of its waters, in which he ''could see trout by the thousands winging about in the emptiness'' at a depth of 80 feet. Because of its mild summer climate and of its picturesque surroundings, its shores have become a popular summer resort. A general account of the scenery of the lake in connection with its complex origin has been prepared by Louderback.[53]

The northern part of the long, down-faulted trough was also cut off from the middle part by volcanic eruptions and there an extensive basin plain, known as Sierra Valley, measuring 19 by 15 miles at an altitude of from 4800 to 4900 feet, has been filled in with heavy detrital deposits. Like the above mentioned Indian and American Valleys, not far to the northwest, this basin plain, which is today marshy in its western part, may have been at various times in its growth overspread by a shallow lake; but today it is drained nearly dry by the successful erosion of the deep gorges of Feather River through the mountains on the west.

The basins of Lake Tahoe and of Sierra Valley thus appear to be of similar origin, but they present certain contrasts. Lake Tahoe at an altitude of 6225 feet is drained to the east through a short gorge cut in its lava barrier; Sierra Valley at an altitude of about 4800 feet is drained to the west through a long canyon cut nearly all across the Sierran range. Lake Tahoe consists of a high-standing body of indrained water, while Sierra Valley consists of a lower-standing body of in-washed detritus. The reason for the second contrast is probably to be found in part in the second lava flow on the flanks of Mount Pluto, by which Lake Tahoe was raised above the level of most of the in-filling detritus that had accumulated in the earlier formed lake; but it is probably because of the first lava flow that the much greater altitude of the Tahoe water-surface than of the Sierra Valley plain is due.

River-Made Lakes

Oxbow Lakes

Various kinds of lakes or sloughs are associated with California's larger rivers. Oxbow lakes, representing cut-off river meanders in various stages of extinction (pl. 26*C*), occur along the Sacramento with radius of quarter or half a mile, and less frequently and of smaller size along the San Joaquin. Pear Slough, near this river, is an excellent example; its name is perhaps taken from its pear-like outline. Here may be mentioned Murphy Lake, occupying a curved and narrow channel 3 miles long, northeast of the junction of Feather River with the Sacramento; also McGriff, Mary, and Horseshoe lakes, apparently of similar origin, which lie east of the Sacramento farther north.

Flood-Plain Marshes

Extensive reed marshes or tulares, known as ''basins,'' occur on the less aggraded lateral parts of the flood plain of the lower Sacramento River (pl. 26*C*). They may be given the appearance of large lakes when

[53] Louderback, G. D., Lake Tahoe, California-Nevada: Jour. Geography, pp. 277-279, 1911.

the river overflows after winter rains. Thus Sutter Basin, 10 by 2 or 3 miles, lies to the east of the river, and Yolo Basin or Slough, 20 by 4 miles, lies to the west; its less aggraded part includes a more permanent sheet of water known as Big Lake, 1½ miles in diameter. The extensive reed growth in these basins is disadvantageous in a region of moderate rainfall where the conservation of water supply becomes important, for the loss of water by evaporation from the growing reeds is many times greater than from a free water surface.[54] A similarly disadvantageous loss is suffered by the Nile where it flows through an extensive papyrus marsh many miles south of its flood plain in Egypt.

Side-Stream Lakes

The shallow valleys of small tributary streams are not infrequently laked back of the alluvial up-building of the flood plains of their trunk rivers; and the backed-up lake water then invades the branches of the tributary valley just as the sea invades branching valleys on a subsiding coast and transforms them into branching bays. Such appears to be the origin of Stone Lake, with 4-mile branches, to the east of the lower Sacramento; and of Cache Slough in the extensive marshes of the Yolo Basin; and of the branched Lindsey Lake, west of the river; also of Plumas Lake, 3 miles long backed up by Feather River flood plain; of Tracy Lake, 2 miles long with several branches, and Sycamore Slough, 3 miles long, backed up by the Mokelumne; and of Kings River Slough, held up for a slender length of 10 miles by the San Joaquin. Although these little lakes have no renown outside of the state, hardly indeed, outside of their county, they provide for their neighboring residents a pleasing departure from the monotonous flatness which characterizes scores and scores of miles of the vast intermont plain, known as the Great Valley.

An example of a laked side stream in a mountain valley is found in the curved range which encloses the Great-Valley plain on the south. The upper part of Grapevine Canyon, the mouth of which holds an extinct landslide lake as told above, has a flat floor heavily aggraded with detritus, perhaps supplied by a landslide in its headwaters. In consequence of this a side valley up stream from old Fort Tejon is ponded in the shallow Lake Castaic; but the lake is often dried off and then one sees only its white, playa-like bed. This lake "is of gruesome memory; for old-timers will tell you that once upon a time some exasperated white men, of the type that modern lynchers are made of, drove a whole village of Indians, men, women, and children, into it, because it was assumed that some of the number were responsible for the murder of the cook and a boy at Fort Tejon."[55]

Many little wet-weather ponds, from a quarter of a mile to a mile across, are found on the plain of the Great Valley between San Joaquin and Kings Rivers, as shown on Conejo, Fresno, San Luis Ranch and Ingomar sheets of the U. S. Topographic Map. Their origin is not clearly understood.

Lakes Barred by Fan Deltas

A few small examples of lakes of this class have already been given; first, the little Blue Lakes that are associated with the above-described

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[54] State of California, Dept. Public Works, Div. Water Resources Bull. 28, 1931. See p. 253.

[55] Saunders, C. J., The southern Sierras of California, Boston, 1923. See p. 74.

Clear Lake of landslide origin; later, the glacial Twin Lakes that are divided by the fan-deltas of opposite side streams. The examples now to be described are of much greater size. The extensive and low-grade detrital fans that are spread out by Kings and Kern Rivers as their contribution to the vast intermont basin-plain of the Great Valley, have obstructed the weak drainage of its drier southern part, and evanescent lakes have thus been formed. Tulare (Spanish for reed-marsh) Lake, south of Kings River fan, was formerly a shallow water-sheet, many miles across; it is now hardly more than a marsh, since the greater part of its water supply has been withdrawn for irrigation.

The following account of the extinct Tulare Lake is condensed from the *Official Historical Atlas of Tulare County,* published in 1892 by the County Supervisors. In the early years of American occupation the lake measured at high water 44 by 22 miles and its area was 760 square miles; in 1891, it had shrunk to 22 by 17 miles and its area was 195 miles. It fluctuated greatly in level, having stood at 220 feet above Suisun Bay in 1862 and 192 feet in 1883. In the flood season of 1862 the attempt was made to run a stern-wheel steamboat from the San Joaquin River to the lake, but the steamer grounded and for many years after the hull and the stern-wheel were incongruous objects on the dry plain. However, in 1875 a small steamboat was built on the lake and used as a pleasure and freight boat for some years; several smaller boats have also been launched there for business and pleasure. In 1891 fish abounded, and terrapin were shipped in large quantities to the San Francisco market. The shallow waters as well as the surrounding marshland were then a favorite resort for water fowl, such as swans, cranes, curlews, duck, geese, and snipe.

Buena Vista and Kern Lakes, 7 by 5 and 6 by 4 miles when flooded, are shallow and vacillating water sheets near the southern end of the Great Valley plain, where they are held by the low delta of Kern River just as Tulare Lake was formerly held by the delta of Kings River. They are said to be reduced to hayfields in summer, and even in winter their flooding is lessened by a canal leading northward where the front of the delta meets the western hills. The plain of Buena Vista Lake, shown on Mouth of Kern topographic map, does not vary 5 feet in altitude across a breadth of 6 miles.

By far the largest delta-barred basin in California, and probably the largest in the world, is found where the northwest end of a great intermont trough of depression is separated by the delta-plain of the Colorado River from its much longer and deeper southeastern part, which is occupied by the Gulf of California. As first described many years ago by Blake,[56] the basin was thought to have been occupied in large part by the head of the Gulf before the delta barrier was built; but it was understood that "occupation of the valley by sea water * * * has extreme antiquity * * * dating back to Middle Tertiary," and that it gradually became fresh because of the flow of the Colorado River into it and its outflow by a channel along the delta front. The modern disappearance of the resulting lake was ascribed to evaporation in the arid climate there prevailing.[57] Later

[56] Blake, W. P., Ancient lake in the Colorado Desert: Am. Jour. Sci., 2d ser., vol. 17, pp. 435-438, 1854.

[57] Blake, W. P., The Cahuila basin and the desert of the Colorado: Carnegie Inst. Washington, Pub. 193, pp. 1-12, 1914. See p. 3.

studies, especially those of Free[58] and Buwalda,[59] recognize the effectiveness of the delta barrier, but explain the basin that it encloses by the progressive depression of the land during the time of delta growth, so that although 2200 square miles of the basin floor are now below sea level, the deepest part being 275 feet below, it has never been overflowed by sea water.

The recent depression of the floor is attested by the occurrence of low fault scarps which cross the piedmont detrital fans built on the basin margin by inflowing wet-weather streams. The salt beds of the basin floor have been shown by Ross[60] to be of such composition that they are best explained, not by evaporation of an enclosed arm of the sea, but of a river-fed fresh-water lake. That such a lake has existed there is shown by its shore lines, about 30 feet above sea level; it must have been formed when the Colorado happened to flow westward into the basin, and the southward outlet of the lake must have followed the margin of the delta where it abuts against the western mountains. The lake necessarily disappeared by evaporation when the river chanced to give up its westward course and flow southward directly to the Gulf.

The present Salton Sea is a temporary water body that was formed on the floor of this great delta-barred basin by the accidental overflow of the Colorado River between 1905 and 1907. The water body then gained a size of 17 by 43 miles and an area of 410 square miles with a maximum depth of 83 feet, and thus became the largest lake in the state. Its area is now slowly decreasing by evaporation and it is destined to disappear. Accounts of it have been prepared by several observers.[61]

Plunge-Pool Lakes

A pool is excavated by the plunging water of a cataract. The plunge-pool of this kind beneath Niagara is about as deep as the falls are high. If the Niagara River were diverted to another course the pool would hold a small lake at the head of the river gorge. Some small lakes of this kind are known in south-central Washington, where the Columbia River, turned in the glacial period from its great northwest bend by the large Okanogan glacier from British Columbia, ran by a more direct course across the lava plains toward its canyon through the Cascade Mountains. It cut back a gorge on that temporary course, at the retreating head of which it plunged down in a great cataract, subdivided by several projecting ledges in the gorge-head cliff. When the invading Canadian glacier disappeared on the return of a milder climate in the postglacial or present epoch, the river resumed its roundabout course and left the temporary course dry, except that several little lakes occupy the pools excavated by the plunging cataract. The site of the vanished cataract is now deservedly protected as a National Monument.

Mention is made of this kind of lake in order to note that miniature water pools of the same kind occasionally occur in the valleys of desert mountain ranges in the southeastern part of the state, where short-

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[58] Free, E. E., Sketch of the geology and soils of the Cahuila basin: Carnegie Inst. Washington, Pub. 193, pp. 21-33, 1914.

[59] Buwalda, J. P., The Salton basin, southern California: Science, vol. 71, pp. 104-106, 1930.

[60] Ross, W. H., Carnegie Inst. Washington, Pub. 193, p. 35-46, 1914. See p. 46.

[61] Mendenhall, W. C., Ground water of the Indio region. . . . : U. S. Geol. Survey Water-Supply Paper 225, pp. 21-24, 1909.

MacDougal, D. T., and others, The Salton Sea. . . . : Carnegie Inst. Washington, Pub. 193, 1914; also Am. Jour. Sci., 4th ser., vol. 39, pp. 231-250, 1915.

Kennan, George, The Salton Sea, 1917.

lived torrents fed by summer cloudbursts excavate minute plunge-pools along their steep courses. The pools are known as "tanks," and also by the Spanish name, "tinajas," or water jars. They are usually more or less filled with boulders and gravel, but they also hold water for a time after a flood and are then the only available water supply for miles around. Where water is priceless, little tinajas may rank as lakes.

The McCoy tanks are in a range of the same name 20 miles west of the lower Colorado. One of them is "a little bowl in porphyry. It is water-tight and holds water for several months." Farther north in the Little Maria Mountains, Mohave tank, in granite, has been "formed by flood waters pouring over a cliff about 15 feet high in the canyon bed"; in October 1917, "a pool of water 12 to 15 feet in diameter and 2 to 3 feet deep stood in the little basin." It has never been known to be entirely dry and is "a favorite watering place for mountain sheep and other wild animals."[62] A detailed account of some remarkable tinajas in Arizona is given by Bryan.[63]

Lake-Like Reservoirs

Artificial reservoirs, constructed for the irrigation of agricultural lands or for the supply of municipal districts or of electric power stations, are truly lake-like in their appearance. Such reservoirs should be deep enough to prevent the growth of reeds, because when reeds are present they cause a great increase of evaporation, as noted above in the account of flood-plain marshes. A number of reservoirs are, indeed, natural lakes artificially enlarged. Some of these water bodies, like the backed-up lakes mentioned in the second preceding section, illustrate very clearly the manner in which the valleys of a subsiding coast are converted into bays. Many small reservoirs are not here listed.

Clear Lake, second largest of its name and already described as occupying a fault basin in the northeastern part of the state, is now enlarged in a reservoir measuring 8 by 3 miles. Big Sage, Thomas and Tule Lake reservoirs, of smaller size, the latter not to be confused with the vanishing Tule Lake farther north, are held in branch valleys of Pit River south of Goose Lake, and Britton reservoir is held in the valley of Pit River itself where it is cut through the northern mountains between Mount Shasta and Lassen Peak. Mountain Meadow and Almanor reservoirs, 6 by 2 and 13 by 5 miles, lie in valleys of the North Fork of Feather River at the northern end of the Sierra Nevada proper, 25 and 35 miles west of Honey Lake: the former submerges part of Big Meadows, above described as the bed of a lava-barred lake; the latter is the largest reservoir in the state.

Farther south and mostly in or near the foothills of the Sierra Nevada, Pardee reservoir, 8 miles long, is on the Mokelumne; Woodward, 3 miles long, is on a small stream east of Stockton, and Melones, 5 miles long, is on the Stanislaus River. The glacial Lake Eleanor, 1 by $1\frac{1}{2}$ miles, in the mountains on an upper branch of Tuolumne River, has been enlarged in a reservoir $2\frac{1}{2}$ miles in length.

On the Upper Tuolumne is the famous Hetch Hetchy reservoir (pl. 34), 8 miles long, in a wonderful trough of the Yosemite type. The proposed construction of this reservoir aroused nation-wide opposition. Many lovers of nature, among whom John Muir was most widely known, protested that the great scenic attractions of the valley would

[62] Brown, J. S., The Salton Sea region, California: U. S. Geol. Survey Water-Supply Paper 497, 1932. See pp. 111, 264, 275, 276.

[63] Byran, Kirk, The Papago country, Arizona: U. S. Geol. Survey Water-Supply Paper 499, 1925. See pp. 123-131.

be diminished if it were laked;[64] but the pressing need of a better water supply for the cities of the San Francisco peninsula, supported by the profitable use of the water in its descent from the high-level reservoir in furnishing electric power, overcame the esthetic protests. Although a reservoir in a mountain valley is evidently a modification of nature, it is not necessarily a disfigurement; and the artificial production of a beautiful reservoir in Hetch Hetchy Valley may be taken as a compensation for the destruction by natural processes of the lake which in prehistoric times beautified the Yosemite.

Farther down Tuolumne River are Don Pedro reservoir, measuring 7 miles in its bent length, and Owens reservoir, 4 miles long. Exchequer reservoir on the lower Merced River is of irregular outline and measures 12 miles in its winding length. In Owens Valley at the eastern base of the southern part of the same range, Upper and Lower Haiwee reservoirs, each about 3 miles long, are on the line of the Los Angeles aqueduct, south of Owens Lake.

Bear Lake, 6 miles long, and Arrowhead Lake, 2 miles long, are reservoirs in the highlands of the San Bernardino Mountains (pl. 38).

All these reservoirs resemble Clear Lake of the northern Coast Ranges, in that their dams obstruct valleys very much as its landslide does; but few reservoirs resemble Clear Lake in having their outflow diverted from the valley by which their waters were formerly discharged. Two exceptional cases somewhat of that kind deserve special mention: One is Echo Lake, south of Lake Tahoe, already mentioned as having its waters diverted from the north and east-flowing Truckee River to the headwaters of the west-flowing South Fork of American River. The other, Pilsbury reservoir, 6 by 2 miles, occupies the branching headwater valleys of Eel River in the Coast Ranges, about 20 miles north of Clear Lake: its outflow runs down the valley to the much smaller Van Arsdale reservoir, but there the outflow is led by a tunnel through a ridge at the head of Potter Valley, where it joins the East Fork of Russian River. In the same region of the Coast Ranges are East Park and Stony Gorge reservoirs, 25 and 35 miles northeast of Clear Lake.

In the San Francisco peninsula south of the Golden Gate the long trough that has been eroded on the San Andreas rift holds two reservoirs, known as San Andreas and Crystal Spring Lakes, 3 and 6 miles long when filled to capacity. In the Mount Hamilton Range southeast of San Francisco Bay, two reservoirs, Chabot, 2 miles long, and Calaveras, 3 miles long, contribute to the pressing need of larger water supply for the growing bay cities.

Santa Barbara reservoir, 4 miles long, is in the valley of the Santa Inez River, north of the east-west mountain range of the same name. Arrowhead reservoir, 2 miles long, and also the artificial enlargement of the above-mentioned Bear Lake, 5 miles long when filled to capacity, are on the highlands of the San Bernardino and San Gorgonio Mountains. Inland from San Diego and not far north of the Mexican boundary are Sweetwater, Lower Otay, Barrett, and Moreno reservoirs, 4, 3, 6, and 3 miles in length. Farther north are the slender Hodge reservoir, 6 miles long,.and the broader Henshaw reservoir, 5 by 4 miles.

Here may be briefly mentioned the shallow water sheets of artificial origin, covering square-mile sections or quarter-sections on the level,

[64] See Muir's article, The Hetch Hetchy Valley, Sierra Club Bulletin, vol. 6, pp. 211-222, 1908, which includes a fine view of the valley in its natural state.

Great Valley plain, maintained by various gun-clubs in order to attract migrating water-fowl. Several of them are shown on the Hamlin School and Miramonte sheets of the U. S. Topographic Map. They remain dry through most of the year, but are flooded by pumping up ground water late in the autumn and so remain into the winter. It is estimated that 1,000,000 wild ducks are shot yearly on these ponds. In their temporary existence they are but little longer lived than the mirages of the desert playas.

The Nile has a lake-like appearance where it spreads over its flood plain above the great dam at Assouan in Egypt. A great and deep-branching lake is now in process of production on the Colorado River by the building of the Hoover Dam in Black Canyon, to which the name of Boulder Canyon, next upstream, is popularly given.

Lake-Like Bays and Lagoons

A number of coastal bays, more or less completely enclosed from the ocean, gain a lake-like appearance. One of them, the Bay of San Francisco, by far the greatest in area as well as in importance in California, is also one of the most famous arms of the sea in the world. Like other famous sea arms, such as the magnificent bay on which the city of Rio de Janeiro is situated in Brazil, or the beautiful bay on which Sydney is situated in Australia, this lake-like bay in California is due to the submergence of former valley-like lowland areas in consequence of a slight subsidence of its district, and the same subsidence converted a former river-cut gorge in the coastal mountains into the famous Golden Gate.

Although the original area of the bay has been considerably diminished by the growth of salt marshes in its shallow shore waters, the main body, San Francisco Bay, still measures 47 by 5 to 12 miles; its northern extension, San Pablo Bay, set apart from the main body by a peninsular arm of the east shore, is 14 miles across; here the muddy water from the rivers of the Great Valley and the clearer water of flood-tide from the ocean are often distinguishable on opposite sides of the bay by their contrasted colors. The innermost reach above Carquinez Narrows is Suisun Bay, 14 by 2 to 6 miles, much shoaled and encroached upon by the marshy delta-lands of the Great Valley rivers.

This great bay may be compared with Clear Lake, in the Coast Ranges 100 miles to the north, because, as has been told on an earlier page, the lake, like the bay, has recently flooded part of an aggraded intermont plain. To be sure, the bay is of salt water at sea level, while the lake is of fresh water at an altitude of 1300 feet; the bay has flooded a large part of an extensive pre-existent plain because that part of the plain was depressed below sea level, while the lake has flooded part of a smaller plain because the drainage outlet of the plain was recently obstructed by a landslide; the bay has become an active center of population, industry and commerce, thereby gaining world-wide fame, while the lake preserves a quiet, rural quality which adds to its charm; but the resemblances of the two as well as their differences deserve recognition.

All the other lake-like bays of the California coast are of much smaller size. Beginning at the north they are as follows: Earl Lake, 1 mile by 6, and Talawa Lake, about 3 miles long, are both, the first behind the second, enclosed by a long, wave-built, smoothly beached sand reef, which swings out to a low rocky headland next north of Crescent City, 10 miles

south of the Oregon line. The two lakes are separated by a narrow strip of sand which may be an earlier-formed reef of somewhat sharper curvature than the outer reef; for such curvature would have suited the beach drift very well before the cliffs to the north were cut back as straight as they are now. On smoothly curved beaches of this sort (pl. 30*A*), in adjustment with the approach of the surf because formed under its control, a long line of breakers plunges almost simultaneously in calm weather for miles together.

In consequence of a slight submergence of the coast, Klamath River is embayed for about 2 miles back from its mouth, which is partly closed by a sand spit. Farther south, where the strongly cliffed coast is adventurously followed by the Redwood Highway high above sea level, three valleys, slightly embayed by the same submergence of the coast, are closed (pl. 30*B*) by heavy sand reefs, on which drift logs abound: the first is Freshwater Lagoon (pl. 31*C*), about a mile across its front; closely following is Stone Lagoon of larger size; third and farther south is Big Lagoon, 3 miles across. The fresh water in these enclosed bays, supplied by streams and springs from the backland, stands a little higher than mean sea level and is discharged by percolating through the enclosing sand reef. Roughly 20 miles farther south the saline waters of Humboldt Bay appear to invade three separate valleys, all enclosed by a single sand reef with a tidal inlet near the middle of its 13 miles of length; the northern and southern embayments are each 4 miles long; the middle one has a much smaller inland reach; all are diminished in area by invading deltas. The city of Eureka lies next south of the northern embayment. Eel River, 5 miles to the south, might also mouth in a bay, had it not been silted up by that good-sized stream, which is many times larger than the little creeks of the Humboldt embayments.

No bays of importance are found in the following 170 miles of the mountainous and boldly cliffed coast; but practically all the streams, none of them of great size, which there issue from the mountains, mouth in small fresh-water lagoons held back by heavy beaches. The streams may break through the beaches at times of flood; at other times their small discharge is accomplished by percolation through the beach sands. One such enlarged stream, the Noyo (pl. 34*B*), offers a striking contrast to its solitary neighbors as it swarms most picturesquely with little fishing boats, for which an artificial cut through the enclosing beach is maintained; not that the slightly enlarged stream is a commodious harbor, but that the cliffed outer coast is absolutely harborless. Several other similarly enlarged streams served as local harbors for the lumber industry some 15 or 20 years ago; but their use has now either decreased or ceased with the decline of lumbering thereabouts.

At the end of the 170-mile stretch of harborless coast Russian River, having made its way in a fine, 13-mile gorge through the coastwise ranges, is enlarged by slight submergence into an estuary a mile or more in length, nearly closed at its mouth by a beach, of which Holway gives a good illustration.[65] Five miles farther on, Bodega Head, originally a 2-mile, rocky island separated by a mile-wide strait from the coast, is now land-tied by a broad beach which is swept out to it from the shore on the north by the long-shore beach drift, thus transforming the strait into a bay open to the south; and a smaller beach, built by a backset or beach

[65] Holway, R. S., The Russian River, a characteristic stream of the Californian Coast Ranges: Univ. California, Pub. Geog., vol. 1, pp. 1-60, 1913.

drift from the shore on the south, nearly encloses the bay; only a narrow tidal inlet is left open next to the end of the rocky island. A striking feature of the bay is the great drove of large dunes, the sands of which, impelled by northwest winds, are slowly climbing over the broader beach and the northern part of the rocky island and invading the bay (pl. 30*C*). The dunes make a delightful summer picnic ground when the inland plain of the Great Valley is blazing hot!

Two miles to the south is the little Estero Americano, or American Estuary, like the Russian River estuary except in being of much smaller size and more completely closed. Then come Tomales and Bolinas Bays, which head against each other in the partly submerged depression that has been worn down on the shattered rock of the San Andreas rift, and which thus nearly insulate the Point Reyes peninsula. The strait that has been transformed into the above-named Bodega Bay lies in the northern continuation of this rift depression. Tomales Bay, opening to the north, is 16 miles long by a mile or so wide; it is imperfectly enclosed by a beach and bar, wave-driven from the north. Bolinas Bay, originally opening to the south and measuring 1 by 4 miles, is now almost closed by Stinson Beach, which is driven obliquely across its mouth by a backset beach drift from the south. The sands for this beach appear to be derived chiefly from the cliffs south of the Golden Gate, whence they travel 20 miles northward, making their way across the entrance to the Golden Gate along its offshore, submarine bar, curved on a 5-mile radius, before reaching the beach.

It is because of this northward shift of the sands that the surviving inlet of Bolinas Bay is at the northwest end of the enclosing beach; and it is because Bolinas is much smaller than Tomales and therefore has weak tidal currents that it is so much better enclosed. Its inlet exhibits a typical example of what may be called a double-headed tidal delta, the outer head of which is built out in a slight salient by the ebb tide and smoothed off by the shore waves, while the much larger and more freely branching inner head of the delta is built by the flood tide in the quiet waters of the bay.

On the south side of Point Reyes peninsula, which makes out between Tomales and Bolinas Bays, is Drakes Estero, a fine embayment 4 miles long, with three arms that branch into as many valleys in the hilly uplands; it is enclosed by a beach formed by backset drift, farther northwest than the one which encloses Bolinas Bay. Three smaller embayments of similar origin are near by; two lie next to the east on the southern coast, and one on the northern coast of the wave-trimmed peninsula.

Five miles south of the Golden Gate is Merced Lake, a true lake in being of fresh water, with two 2-mile arms that enter the hills of the San Francisco peninsula and are enclosed by the broad beach of its ocean shore and by the sand dunes that are swept by the westerly winds from the beach.

Several lagoons lie back of the 25-mile beach and dunes of the wide-open Monterey Bay, the middle of which lies 80 miles south of the Golden Gate. Two of the largest are expansions of Salinas and Pajaro Rivers; but three others, one of which is known as Elkhorn Slough, do not appear to be related to stream courses. Some of these lagoons communicate with the ocean by narrow tidal inlets, but the Salinas lagoon is enclosed by a sand beach, except when floods from winter rains break through it. Near the southern end of the long beach several minute brackish or salt pools,

which are said by Galliher in his account of Monterey Bay to have biological affinities with desert saline lakes,[66] lie back of the invading dunes.

Farther south, the bold and strongly cliffed coast of the Santa Lucia Range extends practically without a bay for 100 miles. All of the streams that here discharge directly to the ocean are of small size; they seem to be slightly embayed by submergence and the little coves are lagooned by beaches. Beyond this long and high range, which runs parallel to the coast, are several shorter ones which trend more to the southeast and head abruptly at the shore. Between them lie aggraded plains, well beached and duned; and back of the first beach of this series is Morro Bay, 3 by 2 miles, the beach of which has been guided by back-set beach drift. The town of San Luis Obispo stands at the head of the plain, 13 miles back from the bay. The next intermont plain, on which Santa Maria is the chief town, is heavily invaded by dunes from its beached front: here, a few miles inland is the small Guadalupe Lake; it was probably of greater size before the invasion of its area by dunes.

Then for over 30 miles southward to Point Conception, for 60 miles eastward along the Santa Barbara coast of the east-west Santa Inez Range, and for 30 miles southeastward along the lower Ventura coast to the east-west Santa Monica Range, no bays or lagoons are mapped, apart from a few small pools, such as those back of the long Hueneme beach of the Oxnard plain in the last 10 of the total 120 miles. Only at the end of that distance is there a narrow, beach-enclosed, tidal lagoon a few miles in length at the western end of the Santa Monica Range.

The 30-mile southern coast of that range is again without embayments; and not until a long beach swings southward from it is a little tide-marsh bay enclosed in the low coast lands; the shore resort of Venice lies on the enclosing beach, 15 miles west of Los Angeles. A few miles farther south rises the promontory of the San Pedro Hills, formerly an island; after it is rounded and the coast trends east again, Wilmington Lagoon, 3 miles long with 3 miles more of tidal marsh, lies back of a long beach that has been built westward by back-set beach drift, so that its tidal inlet is driven against the eastern base of the San Pedro Hill.

The back-set beach drift which has built this beach is, like several other drifts of the same kind mentioned above and one more to be mentioned below, the result of a coastal promontory or salient which holds the dominant southeastward sea current offshore. The lagoon, now provided with an artificial entrance cut through its beach and improved with wharves and docks, serves as the harbor for the growing maritime commerce of Los Angeles, which lies 20 miles inland to the north. The shore resort of Long Beach is at the east end of the lagoon. Beyond it are four more beach-barred lagoons of smaller size.

Farther on still is a marsh that might be a good-sized beach-barred bay, had it not been silted up by the Santa Ana River, the largest stream of southern California. Then comes the bay known as Newport Harbor, 5 miles long at high tide, shut in by a broad, wave-driven and southward-growing beach, on which a summer population gathers; the tidal currents at the harbor entrance are dangerously strong; the Santa Ana River, deflected southward by the wave-driven beach, used to mouth through this bay; it now has an artificial mouth farther north, cut through the long beach that encloses its marshes.

[66] Galliher, E. W., Sediments of Monterey Bay, California: California Div. Mines Rept. 28, pp. 42-79, 1932. See fig. 5 and pl. III.

The following coast is, apart from two small salients, rather smoothly cliffed and beached in a long southeastward curve for over 60 miles; but near the middle of that distance half a dozen small streams, apparently a little drowned at their mouths and more or less marshed, are beach-barred. Next comes Soledad Mountain back of La Jolla, beyond which False Bay is another beach-enclosed embayment, 2 by 3 miles, again with dangerous tidal currents at its inlet. Finally, beyond the southward-stretching peninsula of Point Loma, San Diego Bay is reached, 12 by 2 or 3 miles, enclosed by a long beach, built northward from near the Mexican boundary by a wave drift to the low Coronado Island. This beach, 12 miles in length, is the finest example of its bay-enclosing kind in the state. One of the longest beach-enclosed lagoons in the world stretches northward for scores of miles in a graceful curve from the Rio Grande delta along the low coast of Texas.

CONCLUSION

In closing this review the author desires to remind his readers once more that the study of California lakes is by no means complete. It is therefore eminently possible that further investigations will lead to many new descriptions as well as to corrections in some of the foregoing descriptions. But if lovers of nature, young as well as older, gain an increased enjoyment of California lacustrine scenery by reason of what is here told of its origins, and if some of the more observant among them are thereby incited to make new investigations of the ways in which California lakes are brought into being, the enjoyable labor of gathering the material presented above will be doubly repaid.

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STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF MINES
OLAF P. JENKINS CHIEF

BASEMENT SAMPLES-MINERAL CONTENT IN PERCENTAGE

BY J. C. MAY AND R. L. HEWITT

JOURNAL
VOLUME 44 CHART 1

SP. NO.	COMPANY LEASE WELL NO.	S-T/R	DEPTH	FELDSPARS: QUARTZ	ORTHOCLASE	ALBITE	OLIGOCLASE	ANDESINE	LABRADORITE	BYTOWNITE	AMPHIBOLES: HORNBLENDE	BASALTIC HORN	ACTINOLITE	
HORNBLENDITE														
166	JERGINS OIL CO Cal Grape Nº 18	17-23S/26E	4620-34							1	76			Tremolite T
157	STANDARD OIL CO Nº 72-21	21-29S/29E	4411-21		T				10		55		3	
GABBRO														
112	SHELL OIL CO Marysville Comm Nº C-1	12-16N/1E	6561-63							69	20			
142	AMERADA PET CORP Comm Nº 21-1	21-16S/24E	492		T					63	9			
24	UNION OIL CO Pacific States Nº 21-33	33 28S/25E	13,361							61	2			
147	STANDARD OIL CO KCL Nº 11-44	18 29S/26E	13,469							48	18			
71	STANDARD OIL CO KCL Nº 12-6	30 29S/26E	13,661-664							40	20			Pargasite T
175	BRITISH AMER OIL CO Portals Nº 43-3	3-30S/29E	5535-37							52	11			
DIABASE														
53	SUPERIOR OIL CO. Dodge Land Nº 1	31-20N/1E	7885-88	1	1				50		5			
64	CONTINENTAL OIL CO Drummond Nº 1	36-18S/22E	7904 07						45		31			
77	TURNER PET CO Glaze Nº 1	15-22S/26E	3279-82						40		25		7	
96	TEXAS CO Graham-Loftus Nº 77-1	1-24S/26E	3531-37						62		18			
186	GENERAL PET CORP. Calloway Nº 66	17 29S/27E	10,052-055	3	T			35			10		T	
54	RESERVE OIL & GAS Nº 3	12-10N/19W S.B.	1821-44						45					Tremolite 10
TACHYLYTE														
52	PAC WSTN-GETTY-IND EXPL Cana Nº 1	11-23N/1W	6800±											Basaltic Glass 72
HYPABYSSAL INTRUSIVES														
184	PACIFIC WESTERN OIL CORP. Greenlee Nº 1	25-19N/2E	3475-77					60			17		2	Hematite 2
119	PURE OIL CO Chowchilla Nº 1	7-10S/14E	8373-78	10	5			45			25		T	
13	RICHFIELD OIL CORP. Tulare Comm Nº 1	33-19S/24E	5353-56	6	15			3			15			Glass ? 15
2	CONTINENTAL OIL CO Pixley Comm Nº 1	9-23S/25E	7891-7900	5	2			18			20			
16	RICHFIELD OIL CORP. Kramer Nº 1	34-28S/27E	7728-30	3				31			22			
36	HONOLULU OIL CORP. Nº 76	18-28S/29E	3540	10	2			37						
32	TEXAS CO Camp-West-Lowe Nº 1	7-29S/27E	10,118	5	5			35			12			
41	WESTERN GULF OIL CO K.C.L. Nº B 45	22-29S/27E	10,589	4	8			58			T			
172	AMERADA PET CORP. Wagley Nº 27-14	14-29S/29E	4515	10	5			7						
161	STANDARD OIL CO Nº 45 21	21-29S/29E	5000-02		5			63			20		2	
160	AMERADA PET CORP. S.P. Nº 58-23	35-29S/29E	5328 49		2			47			43		1	
165	GENERAL PET CORP Speed Nº 28-11	11-30S/29E	2902-22	10				60						Glass T
159	H. H. Magee Brockman Nº 3	13-30S/29E	2296 00	20	4			49						
138	MONTEREY EXP. CO Citizens Nº 2	14-30S/29E	2776-82	5	5			30			10			
109	MONTEREY EXP. CO Shell Duff Nº 15	15-30S/29E	3515-20	?T				72						
163	MONTEREY EXP. CO Duff-Shell Nº 1A	15 30S/29E	3344 48		1			45			18			
211	OCEANIC OIL CO Osborne Nº 1	15-30S/29E	3576		2			45			19			
216	MONTEREY EXP CO Duff Nº 10	15-30S/29E	3563		2			40			21			
176	RICHFIELD OIL CORP. Couley Nº 2-1	16-30S/29E	4795-04	2±				41±			12			
152	FEDERAL OIL CO. Federal-Omaha Nº 1	21 30S/29E	5442	2					42		20		3	
74	JERGINS OIL CO Jergins-Texas Fee Nº 15	23-30S/29E	1856					44			15			Tremolite 2
218	CONTINENTAL OIL CO Porter Nº 1	28-30S/29E	4994-99		2			65			5			
89	SHELL OIL CO. Porter-Day Nº 1	29-30S/29E	8386					30			23		3	
50	TIDE WATER ASSOC Di Giorgio Nº 1	3-31S/29E	5486	2	2			44			15			
162	RICHFIELD OIL CORP. Di Giorgio Nº 1-3	3-31S/29E	5303-40		1			48			18		T	
201	UNION OIL CO Di Giorgio Nº 71-3	3-31S/29E	4540-44					40			10			
204	UNION OIL CO Di Giorgio Nº 62-3	3-31S/29E	4682					22			15		5	
113	Di Giorgio Fruit Co. Di Giorgio Nº 48-10	10-31S/29E	6410-16					50			10		2	Tremolite T
206	WESTERN GULF OIL Di Giorgio Nº 1	10-31S/29E	5951	2	2			40			17		3	
106	TEXAS CO. Jewett Nº 2	16-31S/29E	7712-17		5			54			8			
148	CONTINENTAL OIL CO Derby Nº 1	35-31S/29E	8889 99	5	2			40			10		2	

SP. NO.	PYROXENES: HYPERSTHENE	AUGITE	AEGIRINE-AUGITE	ENSTATITE	AEGIRITE	OTHER PRIMARIES: OLIVINE	BIOTITE	MUSCOVITE	ALTERATION MINERALS AND INTRODUCED: EPIDOTE	CHLORITE	CLINOZOISITE	PENNINE	PISTACITE	CALCITE	ALBITE (Secondary)	QUARTZ (Secondary)	SERICITE	PARAGONITE	KAOLIN	LEUCOXENE	LIMONITE	ANTIGORITE	CHALCEDONY	
HORNBLENDITE																								
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71	3	7	4						1	7	10				1				4	T	T	1	1	
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DIABASE																								
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77	5		6		2						9			T				T	T					Graphite T
96	5	10									T			2		T		1	1			T		
186	4		16						10	3½	10	3½		2	T					2½				
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TACHYLYTE																								
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HYPABYSSAL INTRUSIVES																								
184			7						3	4±		4±						1			T			Gold T
119	2						6				T			T	2		1							
13		3					5		T		2			10			1							Andalusite 24
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32			12						5	10	3	2		10										
41									T	5	12	1			2		1		3	T	T		5	
172			1				2	8	T	½	T			1	T		1		1					
161	3						1		½	1	½						1		1					Hematite T
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138		T					5		15	2	10	15		2	1									
109							12		1	1	5	3			5				1				T	Succinite T
163									14	5	15			T						2				
211	3		17						1	3	5			2	2			T						
216		T			4				7	10	7			3					4					
176			12				2		10	3	8			8					2					
152	5	3	5						5	2	4			1		2	5							
74	6		9				2		4	3	10			1	T	3					T			
218			T						6	5	14			3						T				
89	1				12		T		2	4	3	T	2	T	1	3		1						
50	2		10				5		6	T	10			T	T	3								
162					4				10		6	11		T					T					
201	T		15						2	25	5			1	T	T			2					
204	2		12	T					T	25	15				2				2		T			
113	1		4				T		11		16	5		T					T					
206	2		13						1	3	10			3	2				2					
106	3	1	5				7		4	6	6			1					T					
148	1		5				2		18	3	8			T	T	3	T		1					

SP. NO.	ACCESSORIES: CHROMITE	ILMENITE	MAGNETITE	PYRITE	ZIRCON	APATITE	TITANITE	GARNET	REMARKS
HORNBLENDITE									
166			T						Fresh
157			T	T	T	T	T		Minor alteration
GABBRO									
112			⅓	⅓	⅓				Fresh
142	T		3		T	T			Fresh
24	1		1	T		T			Fresh
147				1					Slight alteration
71			1			T			Fractured & veined
175			1						Minor alteration
DIABASE									
53			2½	2½					Fresh
64			1	1					Minor alteration
77			2	4			T		Incipient schistosity
96			T	1					Fresh
186		½		T					Common alteration
54			T						Fresh
TACHYLYTE									
52			½	½					Fractured & veined
HYPABYSSAL INTRUSIVES									
184			T						Diorite porphyry - fresh
119			2			2			Malchite - fresh
13			1			T			Dacite - minor alteration
2									Malchite - altered
16									Malchite - veined & altered
36			1		T				Malchite altered
32			T	1	T				Malchite - altered
41		½			T	½			Malchite - altered
172			½	T				T	Malchite - fresh
161			1	1		T			Diorite aplite - strained
160			1		T	T			Diorite aplite - fresh
165			T		T				Malchite - altered
159			1		T	T			Malchite - partial alteration
138			T	T	T				Malchite partial alteration
109			T		T				Diorite porphyry - altered
163					T				Diorite aplite altered
211				1	T		T		Diorite porphyry - altered
216				T					Diorite porphyry - altered
176				T	T				Malchite altered
152				1					Malchite - altered
74			1		T				Diorite porphyry - altered
218				T	T		T		Diorite porphyry - altered
89				15	T	T			Diorite aplite - mineralized
50				T	T	1			Malchite - altered
162				2					Diorite porphyry - altered
201				T		T			Diorite porphyry - altered
204				T					Diorite porphyry - altered
113				1					Diorite aplite altered
206				T		T			Malchite - altered
106			T		T		T		Diorite porphyry - altered
148			T		T				Malchite - altered

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STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

DIVISION OF MINES
OLAF P. JENKINS, CHIEF

BASEMENT SAMPLES-MINERAL CONTENT IN PERCENTAGE

BY J. C. MAY AND R. L. HEWITT

JOURNAL VOLUME 44 CHART 4

SP NO	COMPANY LEASE WELL NO.	S-T/R	DEPTH	QUARTZ	FELDSPAR	ORTHOCLASE	PLAGIOCLASE	ALBITE	OLIGOCLASE	ANDESINE	LABRADORITE	HORNBLENDE	ACTINOLITE	TREMOLITE	PYROXENE	HYPERSTHENE	AUGITE	ENSTATITE	AEGIRITE
						FELDSPARS						AMPHIBOLES			PYROXENES				
	SCHISTS DERIVED FROM SEDIMENTS																		
133	RICHFIELD OIL CORP Stockton Nº 2	6-1N/9E	6368-76	75			1	T											
22	Schist outcrop-Mariposa County	17-8S/17E		36															
21	Schist outcrop-Madera County	1-10S/18E		10		2													
126	UNION OIL CO. Floto Nº 1	5-11S/18E	2660-70	20		5			T			T							
6	TEXAS CO. Gill Nº 38-16	16 13S/16E	9150	10			15												
173	TRANSCAL Harris Nº1	34-16S/23E	2603	15		8	7					1							
65	AMERADA PET. CORP Lawton Nº58 26	26 17S/19E	11,978-84	60		3	5												
180	W.C. McDuffie Bennett Nº 1	15-18S/23E	5335-42	72			1		T										
111	RICHFIELD OIL CORP. Churchill Nº1	35-20S/24E	5562-66	70		1	2												
100	BRITTAIN TERMINAL Gieck Stevens Nº1	29-20S/25E	4028	38			2												
26	RICHFIELD OIL CORP. Hewitt Nº1	1-21S/25E	3401	48			5												
11	TRICO OIL & GAS Callison Nº1	27 21S/25E	4606-31	39															
154	TIDEWATER ASSOC OIL CO. Hoffman 24	33-21S/25E	5063	50															
114	TIDEWATER ASSOC. OIL CO. C.H. 76-21	21-21S/26E	2560																
69	TIDEWATER ASSOC. OIL CO. C.H. 54-34	34 21S/26E	2714	59	5														
115	TIDEWATER ASSOC OIL CO. C.H. 84 35	35 21S/26E	2228 33	60		1	1												
224	GENERAL PET. CORP. Moran Nº42-30	30-22S/26E	4501-14	50															
117	RICHFIELD OIL CORP. Terra Bella Comm. 1-1	19 22S/27E	2343-53	79															
116	RICHFIELD OIL CORP. Terra Bella Adams 1	29-22S/27E	1912-17	3		2											T		
3	SEABOARD OIL CO Security Nº1	16 23S/25E	4124-27	53	T														
135	BARNSDALL OIL CO. Lombardi-Security Nº1	16 23S/26E	4174-83	3	1														
136	BARNSDALL OIL CO Lombardi-Security Nº1	16-23S/26E	4203-23	37		2	5												
197	SHELL OIL CO. Sunnyvale Comm Nº14-1	29-23S/26E	4822-25	66			5												
149	TANNEHILL Hunsaker Nº1	17 23S/27E	2330	40															
132	TANNEHILL Tannehill Nº1	22-23S/27E	1442-68	20			T					T							
70	DUCOR OIL CO. Muller Nº1	1-24S/27E	1320-44	50			T												
125	LOMI Burrell Nº 1	34-24S/27E	2474 92	65		5	3												
12	SHELL OIL CO. KCL Nº 1	16-26S/28E	1006	62															
39	SHELL OIL CO. KCL Nº 83-35	35-26S/25E	10,045	32	5														
95	A. Bruce Frame Dominion Nº1	18-26S/28E	2476	60															
191	CONTINENTAL OIL CO Reay-U.S.L. Nº1	28-29S/30E	1093-97	39															
87	JERGINS OIL CO. McCowan B-7	13-30S/29E	1223	48															
187	JERGINS OIL CO. McCowan 13A-Nº1	13-30S/29E	1768	32															
188	JERGINS OIL CO. McCowan 13A-Nº2	13-30S/29E	1747	46															
189	JERGINS OIL CO. McCowan 13A-Nº4	13-30S/29E	1820	25			5												
215	JERGINS OIL CO. McCowan 13B-5	13-30S/29E	1605+	8															
60	JERGINS OIL CO. Texas Fee Nº 14	23-30S/29E	2044-47	3					2										
178A	JERGINS OIL CO. Handel Nº1	23-30S/29E	2750-60	66			4								T				
174	TEXAS CO. Hintz Nº1	23 30S/29E	2015	52															
55	BARNSDALL OIL CO. Slininger Nº1	26-30S/29E	2375-77	30			3												
103	MOHAWK PET CORP. Weichelt Nº1	26-30S/29E	2370	30								T							
38	L C MORTON Barlow Farms Nº1	25-31S/29E	5900	53	?														
93	GENERAL PET. CORP. Arvin Nº1	26 31S/29E	7452	30			2												
108	GENERAL PET. CORP. Mattson Nº1	1-32S/29E	8843	78			2												
185	Edward Gieck Woodworth Nº1	30-31S/30E	5164-70	35								T							
20	RICHFIELD OIL CORP. Tejon Nº2	19-11N/18W	4956 59	75			2												
	SCHISTS DERIVED FROM IGNEOUS ROCKS																		
181	TEXAS CO. Jelly Bend Nº 18-8	8-29N/2W	7106-16																
122	RICHFIELD OIL CORP. Chico Nº 1	17 21N/1E	6997-7005						15			5						(Bronzite) 20	
73	TIDEWATER ASSOC OIL CO C.H-87-11	11-22S/26E	2724-34	5					17			T							
33	Geo. W. Stout Nº1	35-22S/27E	1070	9		11						T		11					50
35	AMALGAMATED O & G Konda Nº5	23-24S/27E	1908				49					22	3	2		4			
43	SHELL OIL CO KCL-A-58-8	8-27S/26E	9279-88	5?		5	2					T							
195	GENE REID Lorraine Nº1	2-28S/27E	5874-75	5		?-1				40		47				1			
42	MERIDIAN OIL CO. Meridian Fee Nº 2	23-29S/27E	8530				1					5	2						T
121	AMERADA PET CORP. S P Nº2	15-29S/29E	4385-87	27?		2				28?		2	10		2				10
86	MIDWAY NORTHERN Brown Nº1	29-29S/30E	3509	10					17			20	14						
29	JERGINS OIL CO Hershey Nº9	14-30S/29E	1676	7		5	3	2				½	3						
150	H.H MAGEE Dougherty Nº1	14-30S/29E	2917±				3					10	5	?-3		5			
168	JERGINS OIL CO. Hershey Nº S-1	14-30S/29E	2172-92	4		3				10		18	6						
169	JERGINS OIL CO Hershey Nº 3	14-30S/29E	2372-77							2		38							2
167	JERGINS OIL CO. Dougherty Nº 6	14-30S/29E	2590-96							3		20	3			9			2
170	MONTEREY EXPL CO. Citizens Nº 3	14-30S/29E	2902-11									39				10			5
179	MONTEREY EXPL CO Citizens Nº 2	14 30S/29E	2832-40							30		5		9		6			8
123	JERGINS OIL CO Dougherty Nº 5	14-30S/29E	2655	10		5												18	
190	JERGINS OIL CO. Hershey Nº 9A	14 30S/29E	1834-39			2				16									
137	H.H MAGEE Jergins-Dougherty Nº5	14 30S/29E	2655			4				45		40				3			
139	MONTEREY EXPL CO Duff Nº9	15-30S/29E	3619+				24					3				1	2		
158	JERGINS OIL CO Texas Fee Nº 25	23 30S/29E	3025-41							39		5			?-T				
177	JERGINS OIL CO Jergins Texas Fee 17	23 30S/29E	1805			4				30						?-T	1		
178B	JERGINS OIL CO Handel Nº1	23-30S/29E	2623				20					2	9						25
31	TEXAS CO Bastian Nº1	34-30S/29E	4608									25	5			3			
140	DiGiorgio Fruit Corp 35-10	10-31S/29E	6185		?-6		T					?-T	25			?-2			
92	SHELL OIL CO Greer Nº1	15-31S/29E	6171									20	3			1			
48	TW Burnham Chiquita Nº2	34-12N/18W	1675±	15		7						T						10	

SP NO	MICA	BIOTITE	MUSCOVITE	EPIDOTE	CHLORITE	PENNINE	CLINOZOISITE	CLINOCHLORE	SIDERITE	CALCITE	QUARTZ (Secondary)	ALBITE (Secondary)	SERICITE	PARAGONITE	KAOLIN	LIMONITE	SERPENTINE	TALC	CHALCEDONY	LEUCOXENE	OPAL
	PRIMARY & SECONDARY					ALTERATION MINERALS AND INTRODUCED															
SCHISTS DERIVED FROM SEDIMENTS																					
133					T		7			T	5		1			5					
22		T	1											1	1	47			10		
21													T			50					
126		44	T		5					5							20				
6					60					8					1	1					
173		1	3								35		13								
65		3	2		2		T			5			T		T	3					
180			T		T								15		1						
111	3				4					5					10					T	
100		T	5		T						X		25								
26		8	2		4																
11		T			2								58		T					T	
154		5		T	29		T						10								
114				T	20				34	1	21		24								
69		T	3		3					1			9			T					
115			5	T	3		T						20								
224		42	3																		
117		15	4		1																
116		T		T	T		T			T									(95 or glass)		
3					T								5		T						
135			1							74					1						
136		T	1							T			15			T					
197		2	T		15								2								5
149		42	3		5											T					
132		53	4	T	2								6		5	1					
70		2	3		3								35								
125		25																			
12		15	T		10						3										
39	30				10					T					5						
95		15			15															T	
191		3	56		T						2				T						
87		10	30		1						5		5								
187		5	13		5						24		T								
188		5	20		2								T								
189		20			20					18	X	7									
215		5	7		10						65										
60		T		T	1		T			87											
178A		5		18	T		5			T	X	2								T	
174		10	17		1								3			T				2	
55		25	12		16		T								2						
103		50	5	T	5	2				T	3		T								
38		1	1		25											5					
93		1	T	T	1					60						5					
108		10	2		3		1								1½						
185		10	T																		
20		15	4																		
SCHISTS DERIVED FROM IGNEOUS ROCKS																					
181		T								T							87		11		
122		8		3	5	14	5							3	2		18			1	
73		T		T	59	X	T			2	10			4			T			?1½	
33					2														16		
35			7	T	1		5			T				1	2					1	
43				10	5		4			1	38				10		T		19	T	
195		T		½	1	1	½			2											
42				3	27	20	2			1	12	?-T	1		26						
121				4	6		3			1					T						
86		2		1	1		5			T	10	T		T	10						
29		10			30	4	5			T						T	23	1			
150		1		20	5		23			15	8				2	T					
168				1	3	16	2			15	3	6									
169		2		1	7	10	7				23	T	T								
167		½		8	16		17½			20						T				1	
170				10	2		30			3	T										
179				4	25		10				2				1			T			
123		2	1		15					5	8		T			T	35				
190		20		T	5					40	15	1									
137				1			6			T			1								
139				25	25		15								5						
158		7		10	14		8			8					8						
177		18		8			5			T	10	11			8	5					
178B				5	20	5	5			1		3			5						
31				5		20	42								T						
140				1	28		10			25	T				2						
92		T		18	5		18			T	25				10						
48		23	3			3							6		T	2	30				

SP NO	ANDALUSITE	GRAPHITE	SILLIMANITE	TOURMALINE	SUCCINITE	ILMENITE	CHROMITE	MAGNETITE	HEMATITE	PYRITE	ZIRCON	APATITE	GARNET	TITANITE	MONAZITE	ROCK DETERMINATION
								ACCESSORIES								
SCHISTS DERIVED FROM SEDIMENTS																
133								1			T	T			5	Quartzite with clinozoisite and monazite
22			2	T				2			T					Limonite-quartz schist with sillimanite
21	37	1						T				T				Limonite andalusite-quartz schist
126								½		T	T	½				Serpent. biotite-quartz schist
6		3						2								Chlorite plagioclase quartz schist (boulder)
173		17								T	T					Quartz-graphite sericite schist
65		17														Shale or argillite
180		7						1		3	T					Quartz-sericicite schist w/ graphite
111		3		T				T		2	T					Quartz schist with graphite
100		28								2						Quartz-mica-graphite schist
26		31						2		T	T					Quartz-graphite schist w/ biotite
11								½		½						Sericite-quartz schist (Phyllite)
154		5						T		1	T					Quartz chlorite-sericite schist graphite & biotite
114										T	T					Siderite-mica-quartz-chlorite schist
69		20														Quartz-graphite mica schist
115		10						T		T						Quartz-mica-graphite schist
224		5								T						Quartz-biotite schist
117								½		½		T				Quartz biotite schist w/ muscovite
116		T									T					Altered tuff?
3		42								T						Quartz graphite schist with sericite
135										20						Limestone (impure)
136		40									T					Graphite quartz-mica schist
197		5						T								Quartz-chlorite schist with graphite
149		10								T	T					Biotite-quartz-graphite schist
132		7						2		T						Biotite-quartz schist w/ white mica & graphite
70		7						T								Quartz-sericite schist with graphite
125								2			T	T				Quartz-biotite schist
12		8						T		2	T					Quartz biotite chlorite schist w/ graphite
39		18									T	T				Quartz mica-graphite schist w/ chlorite (Boulder)
95		?-5				?T				5						Quartz-biotite-chlorite schist w/ graphite?
191	T									T		T				Muscovite-quartz schist w/ biotite
87		T						1		T						Quartz-muscovite schist w/ biotite
187		20						1		T		T				Quartz graphite muscovite schist w/ biotite
188		25								2		T				Quartz-graphite-muscovite schist w/ biotite
189										5	T					Quartz-biotite schist with albite
215		4						1					?T			Catataclastic, quartz-chlorite schist
60								1		5	1					Altered schist?
178A						T							T			Quartz-epidote schist w/ biotite
174		15			?-T	?-T				T						Quartz muscovite-graphite biotite schist
55								12								Quartz-mica chlorite-magnetite schist
103		2			?-2								1			Biotite-quartz schist with chlorite
38		15					T					T				Quartz-chlorite graphite schist
93								½		½	T					Impure limestone (breccia)
108		1						1		½						Quartz-biotite schist
185		25		30						T						Quartz tourmaline-graphite biotite schist
20								T		3	½	½				Quartzite
SCHISTS DERIVED FROM IGNEOUS ROCKS																
181								1	T	1						Serpentine
122						1					T			T		Altered diorite porphyry
73						½					1					Chlorite-andesine schist with quartz
33								1								Aegirite-tremolite-orthoclase schist w/quartz
35						2				1						Plagioclase-hornblende schist w/muscovite
43						T				1	T					Quartz-epidote schist
195								½		½		T		T		Hornblende-andesine schist
42																Chlorite schist
121								1		4						Plagioclase-quartz-aegirite-actinolite schist
86								5		5	T					Amphibole oligoclase?-quartz schist
29								3		3	½	T				Serpentinized-chlorite-biotite schist
150								T		T						Epidote-amphibolite schist
168								7		6						Hornblende-chlorite-plagioclase schist
169										8	T	T				Hornblende schist with pennine
167					T	T				T	T	T				Epidote-hornblende-chlorite schist
170										1						Epidote (clinozoisite) hornblende-pyroxene schist
179								T								Chlorite andesine-clinozoisite schist w/aegerite?
123								1			T					Serpentinized malchite?
190										1						Biotite andesine-quartz schist
137										T	T					Andesine-hornblende schist
139											T					Epidote-plagioclase-chlorite schist w/hornblende
158					1-?			T			T					Andesine-epidote-chlorite schist w/ biotite
177								T			T		T			Andesine biotite schist with albite
178B																Aegirite-plagioclase-chlorite schist
31										T		T		T		Clinozoisite-amphibole chlorite schist
140								T		1	T	T				Chlorite-actinolite-clinozoisite schist
92										T						Epidote-quartz-amphibole schist
48				1				1			T	T				Serpentinized malchite

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DIVISION OF MINES
OLAF P. JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

JOURNAL
VOLUME 44 PLATE 23

REPRINTED FROM CALIFORNIA JOURNAL OF MINES AND GEOLOGY
JANUARY - APRIL 1933.

LIST OF LAKES SHOWN ON "LOCATION MAP OF CALIFORNIA LAKES"

Name	Map No.
Alkali Lakes	15
Almanor Reservoir	24
Arrowhead Reservoir	111
Barrett Reservoir	128
Bear Lake	112
Big Lagoon	6
Big Lake	60
Big Sage Reservoir	14
Blue Lake, Lassen County	17
Blue Lakes, Lake County	41
Bodega Bay	63
Boiling Springs Lake	23
Bolinas Bay	59
Borax Lake	43
Bristol Lake	115
Britton Reservoir	20
Buena Vista Lake	102
Bumpus Hell	23
Butte (Bidwell) Lake	23
Cache Slough	62A
Calaveras Reservoir	66
Cascade Lake	30A
Castaic Lake	108
Chabot Reservoir	66
China Lake	101
Clear Lake, Lake County	42
Clear Lake, Modoc County	16
Clear Lake Reservoir, Modoc County	10
Cliff Lake	23
Cluster Lakes	23
Crystal Spring Lake	58
Death Valley	96
Deep Spring Valley	98
Desolation Lake	87
Dollar Lake	114
Don Pedro Reservoir	74
Donner Lake	29
Drakes Estero	60
Dry Lake, Inyo County	99
Dry Lake, Kern County	110
Dry Lake, San Bernardino County	113
Eagle Lake	21
Earl Lake	1
East Park Reservoir	40
Echo Lake	34
Eleanor Lake	76
Elizabeth Lake	109
Elkhorn Slough	90
Elsinore Lake	119
Emerald Lake	23
Emigrant Lake	86
Estero Americano	62
Exchequer Reservoir	73
Fallen Leaf Lake	33
False Bay	124
Freshwater Lagoon	4
Garnet Lake	81
Gold Lake	27
Goose Lake	12
Guadalupe Lake	106
Haiwee Reservoirs	95
Hat Lake	23
Helen Lake	23
Henshaw Reservoir	122
Hetch Hetchy Reservoir	76
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Honey Lake	26
Horseshoe Lake, Shasta County	23
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Huckleberry Lake	85
Humboldt Bay	7
Independence Lake	28
Juniper Lake	23
Kern Lake, Kern County	103
Kern Lakes, Tulare County	93
Kings River Slough	89
Klamath River Embayment	3
Lindsey Lake	62
Loon Lake	32
Lost Lake	18
Lower Klamath Lake	8
Lower Otay Reservoir	127
McCoy Tanks	117
McGriff Lake	46
Manzanita Lake	23
Mary Lake	47
Medicine Lake	11
Melones Reservoir	70
Merced Lake, San Francisco County	56
Merced Lake, Mariposa County	78
Mirror Lake	77
Mohave Tank	116
Mono Lake	82
Monterey Bay	91
Moreno Reservoir	129
Morro Bay	105
Mountain Meadow Reservoir	25
Murphy Lake	48
Newport Harbor	120
Noyo River Embayment	36
Owens Lake	94
Owens Reservoir	72
Pardee Reservoir	69
Pear Slough	72A
Pillsbury Reservoir	38
Pleasant Lake	31
Plumas Lake	48
Rainbow Lake	23
Reflection Lake	23
Russian River Embayment	64
Saline Valley	97
Salton Sea	118
San Andreas Reservoir	57
San Diego Bay	125
San Francisco Bay	65
San Pablo Bay	54
Santa Barbara Reservoir	107
Searles Lake	100
Shadow Lake	23
Silver Lake	35
Snag Lake	23
Soda Lake	104
Stone Lagoon	5
Stone Lake	61
Stony Gorge Reservoir	39
Suisun Bay	53
Swan Lake	23
Sweetwater Reservoir	126
Sycamore Slough	67
Tahoe Lake	30
Talawa Lake	2
Tenaya Lake	79
Thomas Reservoir	13
Thousand Island Lake	80
Thurston Lake	44
Tilden Lake	84
Tomales Bay	61
Tracy Lake	68
Tulare Lake	92
Tule Lake (Rhett Lake)	9
Tule Lake Reservoir	19
Twin Lakes, Mono County	83
Twin Lakes, Shasta County	23
Van Arsdale Reservoir	37
Volcanic Lakes	88
Wilmington Lagoon	121
Woodward Reservoir	71

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF MINES
OLAF P JENKINS CHIEF

BASEMENT SAMPLES - MINERAL CONTENT IN PERCENTAGE

BY J. C. MAY AND R. L. HEWITT

JOURNAL VOLUME 44

					FELDSPARS						AMPHIBOLES				PYROXENES					OTHER PRIMARIES
SP NO	COMPANY LEASE WELL NO	S-T/R	DEPTH	QUARTZ	ORTHOCLASE	ALBITE	OLIGOCLASE	ANDESINE	LABRADORITE	BYTOWNITE	HORNBLENDE	BASALTIC HORN.	ACTINOLITE		HYPERSTHENE	AUGITE	AEGIRINE-AUGITE	ENSTATITE	AEGIRITE	OLIVINE
	DIORITE																			
72	BUTTES OILFIELD CO LTD Sophie Davis N°2	35 16N/1E	7011-14							50	33				1	1			5	
61	BANKLINE OIL CO Community N°1	1-4N/6E	5758 65					64			5				1	20		4		
130	UNION OIL CO Archibald N°1	14 10S/18E	700-10		10			77			5									
127	UNION OIL CO Foss N°1	6 12S/20E	1128-34					49			30						T			
143	AMERADA PET CORP Community N° 28 1	28 16S/24E	905					68			7				1		19			
	QUARTZ DIORITE																			
134	RICHFIELD OIL CORP Stockton N°1	5 1N/8E	8539-44	12	3			50												
75	BARNHART-MORROW CORP Arnold N°1	22 10S/17E	3059-72	15	2			45			13				2					
59	West Little Table Mountain	33 10S/20E	outcrop	5				44			45					1				
45	Sample A-2	11 11S/21E	outcrop	10	?1			68			9				1					
14	SUPERIOR OIL CO White N°1	29-16S/22E	5466 68	16				65			3±	2±				1				
171	Winnifred Schneider Pritchett N°1	1 17S/24E	1144-47	5	10			62			6		?1				2			
101	HUB OIL CO Andrews N°1	27-22S/27E	1485	10	5			66			5		T							
118	RICHFIELD Terra Bella Hastings N°1	28 22S/27E	1734 41	12	5			69			5				1					
28	Geo W Stout Stout N°1	35 22S/27E	1002	24				68												
110	Haggerty and Caine N°1	7 23S/28E	7004-40	15	2			68			6					2				
19	VEDDER BROS Hart N°1	22 24S/27E	2312	4	2			42												
182	OKANE & Brain Wheeler N°1	20 25S/26E	6685-95	3	T			2			15					2				
15	SHELL OIL CO Bell N° 52	21-25S/26E	6337	3	T			55			15								2	
79	AMERADA PET CORP Jasmin-C	1-25S/27E	1873-83	25				20						Pyroxene T						
78	AMERADA PET CORP Jasmin-A	2 25S/27E	1895 96	15	5			50			7				T		2			
5	A E. Dawson N°1	3-25S/27E	2650	20				7			5				5					
120	WESTERN GULF OIL Richgrove Comm N°1	4 25S/27E	2643 53	25	1			40			15									
124	WESTERN GULF OIL Quinn N° 4 1	8 25S/27E	3565	15	2						T									
44	Dilimar Quinn N°1	15 25S/27E	2907	10	T			47			10				2	5				
76	BARNHART MORROW CONS Quinn N°1	15 25S/27E	2823-26	15	1			59			T									
81	Cochrane Bishop N°1	31-25S/27E	4850	13½				30			13				10		5			
83	AMERADA PET CORP Jasmin-G	7 25S/28E	1651-61	10	5			49			T			Spodumene ? 1	3					
37	Hayes Jenkins Inv Co Corehole	17 25S/28E	1170+	15	10			2			2			Pyroxene T						
94	C C M O CO Villard N°A-1	31-25S/28E	2552	5	T			T			35				3					
17	TIDE WATER ASSOC Strine N° 32 15	15 26S/26E	6520 36	25	T			56			2					T				
82	SUPERIOR OIL CO Smith N°1	11 26S/27E	3446	17	2			35			5				10					
62	SHELL OIL CO Vedder N°1	9-27S/28E	5099-3117	23	2			42			1									
18	SEABOARD OIL CO Fuhrman N°1	28 28S/28E	5251-61	38	T			52			T									
67	RANGE OIL CO N°1	36-28S/28E	4693	10	10			67			T						2			
156	RICHFIELD OIL CORP S.P N° 15-1	31-29S/30E	5260	3	10			71			T			Riebeckite T	1					
88	JERGINS OIL CO McCowan N° 13 1	13 30S/29E	3739	7	6			65												
99	JERGINS OIL CO Ross N°2	24-30S/29E	1219	12	10			65												
66	Mettler & Sons Mettler N°1	25 30S/29E	1740 55	12	3			70												
98	Berry Edison Duff N°1	25-30S/29E	1335	10	10			65												
104	PETROLEUM PROD CO. Welsh N°1	35-30S/29E	2679	14	8			69												
151	RICHFIELD OIL CORP Cauley N°1	36-30S/29E	1302-04	10	6			72			2					1				
153	INDEPENDENT EXPL CO Mettler N°1	19 30S/30E	1399	10	10			73							T					
102	R & R DEVELOPMENT CO N°1	29 30S/30E	1104	13	5			64			2				1					
90	R & R DEVELOPMENT CO N°3	32 30S/30E	862	15	7			70			2					T				
63	Di Giorgio Fruit Co Di Giorgio N°4	10 31S/29E	5843	5				44			17				10	4				
8	Di Giorgio Fruit Co Di Giorgio N°1	12-31S/29E	2253 58	10	10			67			1									
9	Di Giorgio Fruit Co Di Giorgio N°2	12 31S/29E	3125	14	10			69						Pyroxene 2						
47	Rock Pile	4 31S/30E	outcrop	15	2			68												
58	Di Giorgio Fruit Co Di Giorgio N°3	7-31S/30E	1635	20	3			71												
56	Basement Sample	13-31S/30E	outcrop	20	2			42			10									
105	HALL-BAKER McCowan N°1	20 31S/30E	1883	20	8			21			15						2			
57	Basement Sample	24-31S/30E	outcrop	18	2			59			8									
49	Basement Sample	16-32S/30E	outcrop	32	5			44												

	OTHER PRIMARIES		ALTERATION MINERALS AND INTRODUCED																ACCESSORIES								
SP NO	BIOTITE	MUSCOVITE	EPIDOTE	CHLORITE	CLINOZOISITE	PENNINE	PISTACITE	CALCITE	ALBITE (Secondary)	QUARTZ (Secondary)	SERICITE	PARAGONITE	KAOLIN	LEUCOXENE	LIMONITE	ANTIGORITE	CHALCEDONY		CHROMITE	ILMENITE	MAGNETITE	PYRITE	ZIRCON	APATITE	TITANITE	GARNET	REMARKS
DIORITE																											
72	3		T	2	3			T					T								1	1					Fresh
61			T	2				1		T							1	Analcite ? 1			1		<1				Fractured but fresh
130	8	T	T	T																	T	T	T			T	Fresh
127	8			8	2			1			1								T		1		T	T?			Slight alteration
143			T																		T	5		T			Fresh
QUARTZ DIORITE																											
134	10	1	2	6				1			5		10					Allanite ? T									Weathered-quartz intergrowths
75	5					T		T			T		2				6				T	T	T		T	T	Fractured & weathered
59			1	T	1							1			1				<1				<1				Fresh
45	8					3			T												T		T	T			Fresh
14	12		T	<1	T			T	T			<1									T		T	T		T	Fresh
171	12			1	T			T			T										T	½	½	T	T	T	Fresh; Myrmekitic intergrowths
101	12		T	1	T			T			1		T								T			T		T	Fresh, reaction rims
118	6		1	T							1						T	Hematite ? T			T	T	T			T	Weathered
28	6			T	T				2		T										T		T				Fresh
110	6		T		1						T										T	T		T		T	Fresh
19	20			10	T						4		10		6						T	T		2		T	Weathered
182	10			5	14	T		1			5		38½		½		2				½	½	T	1			Weathered
15	21		T	1				1			1				T				T		1			T			Fairly fresh
79	20	T		11±								11±	11±		T							½	½	1			Weathered
78	10	T	1	2	1				1		3±		3±								T	T	T	T			Weathered
5	2	7½+	7½±	7½±	7½±	7½±					7½±		7½+		7½±						1		T	T		T	Weathered
120	3		T	3				12									1				T	T	T	T			Fractured & veined
124	14			34	T	T		5			5		20	1	4			Siderite ? T			T		T				Weathered
44			3	10	2						10										1			T			Weathered
76	8	T	T			2		3	T		9		3					Tourmaline T			T	T	T	T			Fractured
81	T	T	T		1	3			T			2	20				1		1		T	T		½		T	Weathered
83	10	2	4	6				5			2½		2½					Tourmaline T			T			T		T	Fractured & veined
37	T	25	1	40	2						3														T		Weathered
94	1	2	11±	11+	11±	11±					10+				T						T	T	T				Weathered
17	15		T	T	T						T		T					Monazite T			1		T	1			Fresh
82		2	5	6	8			10						T							T				T	T	Fractured & veined
62	25				T	1		5						T						T		T	½	½		T	Fractured
18	5	1		1	T			T			T						1				T	T	T	T		1	Fresh
67	9	T	T	1	1						T										T	T	T	T			Fresh
156	10	½	2	1	1	½		T													T	T	T	T			Fresh
88	10	T	T		T	T		1			5		2				2						1	1		T	Fresh
99	8			2½+	T	T					2½±						T				T		T				Fresh
66	10			1									3				T						⅓	⅓		⅓	Fresh
98	15			T									T		T						T			T		T	Fresh
104	6			2				T			T		T										1	T			Fresh
151	5				T		1	T			1		1								1		T	T		T	Fresh
153	5	1			T						T		T										T	1		T	Fresh
102	10			T							T		2				1				1	T	1	T		T	Fresh
90	5						T				T										1			T		T	Fresh
63			2		13			1				1	2									1		<1			Altered incipient schistosity
8	10	T	T	T				T			½		½								⅓		⅓	⅓	T	T	Fresh
9	3		T	⅓	T			T			⅓		⅓										T	1			Fresh
47	10	2		1							T		1					Hematite T					⅓	⅓		⅓	Fresh
58	5				T	1					T										T		T	T		T	Fresh
56	15		T		T			1	8		½				½								½	½		T	Fresh
105	15				1	T			10				2				5				⅓	T	⅓	⅓		T	Fresh some veining
57	12																						T	1		T	Fresh
49	15		T				T		3									Hematite ? T			⅓		⅓	⅓			Fresh shows stress effects

JBB

STATE OF CALIFORNIA
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DIVISION OF MINES
OLAF P. JENKINS, CHIEF

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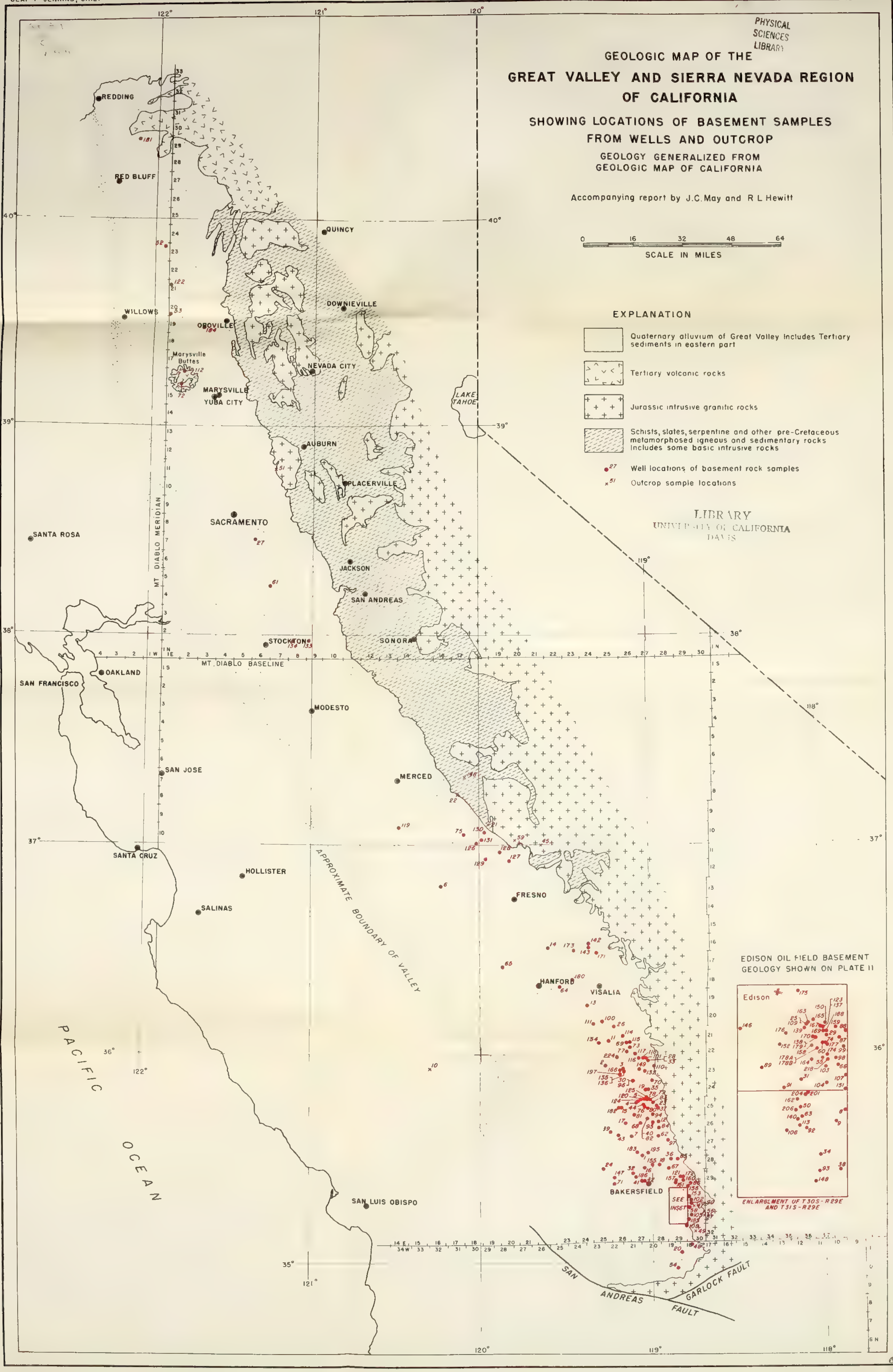
BY J. C. MAY AND R. L. HEWITT

JOURNAL VOLUME 44 CHART 3

				FELDSPARS							AMPHIBOLES				PYROXENES					OTHER PRIMARIES			ALTERATION MINERALS AND INTRODUCED																ACCESSORIES								
SP NO.	COMPANY LEASE WELL NO.	S-T/R	DEPTH	QUARTZ	ORTHOCLASE	ALBITE	OLIGOCLASE	ANDESINE	LABRADORITE	BYTOWNITE	HORNBLENDE	BASALTIC HORN.	ACTINOLITE		HYPERSTHENE	AUGITE	AEGIRINE-AUGITE	ENSTATITE	AEGIRITE	OLIVINE	BIOTITE	MUSCOVITE	EPIDOTE	CHLORITE	CLINOZOISITE	PENNINE	PISTACITE	CALCITE	ALBITE (Secondary)	QUARTZ (Secondary)	SERICITE	PARAGONITE	KAOLIN	LEUCOXENE	LIMONITE	ANTIGORITE	CHALCEDONY		CHROMITE	ILMENITE	MAGNETITE	PYRITE	ZIRCON	APATITE	TITANITE	GARNET	REMARKS
	GRANODIORITE																																														
129	UNION OIL CO Pacific Land Co. Nº 1	35-11S/18E	3660-70	10	15			26			13								2		8						2	5	T		T						18				1	T	T	T			Fractured & veined
128	UNION OIL CO Smith Nº 1	22-11S/19E	1165-75	20	10			30													25					3	5	1			5							Stilbite T					1	T		T	Slight weathering
80	C C M.O Jasmin Nº 1	23-25S/27E	2265	25	16			49											T		3	1	T		T						3		1									1		⅓	⅓	⅓	Fresh
68	Fred Jasper Jasper Nº 1	16-26S/27E	4419-21	10	9			40								T					3	2		3			7				12½±		12½±														Weathered
155	TIDE WATER ASSOC Luck Nº 154	30-28S/28E	5994-98	10	17			56			2										10	½	½	½	T			T			½										½	1	½	½		½	Fresh
85	PEBBLE BEACH OIL CO. Olcese Nº 1	16-28S/29E	1671	30	5			24			10				3								T		3	5		T			T				T		20	Tourmaline T			T						Altered & veined
	QUARTZ MONZONITE																																														
131	UNION OIL CO Moses Nº 1	27-10S/18E	1720-30	5	29		50?														10	1	½		½				T		3										⅓		⅓	⅓			Fresh
7	C C M.O Famoso Nº 12-1	12-27S/26E	6855	20	20		41														9		T	5	1						3		T					Glass ? T				T	1			T	Fresh
97	SUPERIOR OIL CO Nº 1	13-27S/28E	1810	5	25			40													10	T		1	T	T					5						13				⅓		⅓	⅓			Fractured & veined
107	OHIO OIL CO Cauley Nº 2	36-30S/29E	1247	25	25		35				T										3		T		2	1		2		T	7										T	T	T	T			Weathered
	GRANITE																																														
51	Rocklin Quarry	19-11N/7E	outcrop	55	8½		30									½					2	1		½				½	½		½		½								¼			¼		T	Fresh
4	TIDE WATER ASSOC Quinn Nº 46	8-25S/27E	3776-86	35	21		3														5		2	T	5	T					3			1			25			T			T	T	T		Fractured & veined
23	WILSHIRE OIL CO Amalgamated Nº 1	17-25S/28E	1306	20	5						T										10	1		29	10						T		T				25					T	T				Weathered & veined
84	SHELL OIL CO Knapp Nº 2	28-26S/28E	2262	13	50		7														15	2		T		T			2		2						8	Tourmaline 1					T				
	ANDESITE																																														
27	INDEPENDENT EXPL CO Unit Plan Nº 1	19-7N/6E	4801					56														5	5	5	5	5		10									5				3		T	1			Veined & altered
183	STANDARD OIL CO Nº 34-5	5-28S/27E	7185					1			22				2		3		4		30	2	T	35	T							T										T	T				Altered
1	STANDARD OIL CO Fee Nº 42-9	9-28S/27E	6209					38			60				T								T		½								½								1						Fresh
164	RICHFIELD OIL CORP. Lawson-Bennett Nº 1	26-30S/29E	3487-92					T								3					T		9	75	7			T		4					2												Highly altered
91	OHIO OIL CO Derby B Nº B-1	33-30S/29E	5867					68													2	1	T	10	T			7		5			2				2	Aragonite 3			T		T				Altered & veined
34	L C. Morton Jewett Nº 1	23-31S/29E	6697-99					60±			23±					1					15±				T			1		T											T			T			Fresh

J.B.B.


GEOLOGIC MAP OF THE
GREAT VALLEY AND SIERRA NEVADA REGION
OF CALIFORNIA
SHOWING LOCATIONS OF BASEMENT SAMPLES
FROM WELLS AND OUTCROP
GEOLOGY GENERALIZED FROM
GEOLOGIC MAP OF CALIFORNIA
Accompanying report by J.C. May and R L Hewitt
SCALE IN MILES
0
16
32
48
64
EXPLANATION
Quaternary alluvium of Great Valley includes Tertiary sediments in eastern part
Tertiary volcanic rocks
Jurassic intrusive granitic rocks
Schists, slates, serpentine and other pre-Cretaceous metamorphosed igneous and sedimentary rocks Includes some basic intrusive rocks
Well locations of basement rock samples
Outcrop sample locations
EDISON OIL FIELD BASEMENT
GEOLOGY SHOWN ON PLATE II
Edison
ENLARGMENT OF T30S-R29E
AND T31S-R29E
REDDING
RED BLUFF
QUINCY
WILLOWS
OROVILLE
DOWNIEVILLE
Marysville
Buttes
MARYSVILLE
YUBA CITY
NEVADA CITY
LAKE TAHOE
AUBURN
PLACERVILLE
SACRAMENTO
SANTA ROSA
JACKSON
SAN ANDREAS
STOCKTON
SONORA
MT. DIABLO BASELINE
MT DIABLO MERIDIAN
OAKLAND
SAN FRANCISCO
MODESTO
SAN JOSE
MERCED
SANTA CRUZ
HOLLISTER
SALINAS
FRESNO
APPROXIMATE BOUNDARY OF VALLEY
HANFORD
VISALIA
PACIFIC
OCEAN
BAKERSFIELD
SEE INSET
SAN LUIS OBISPO
SAN ANDREAS FAULT
GARLOCK FAULT
122°
121°
120°
119°
118°
40°
39°
38°
37°
36°
35°

STATE OF CALIFORNIA
EARL WARREN, Governor

DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

Vol. 44 JULY 1948 No. 3

CALIFORNIA JOURNAL OF MINES AND GEOLOGY

STATE OF CALIFORNIA
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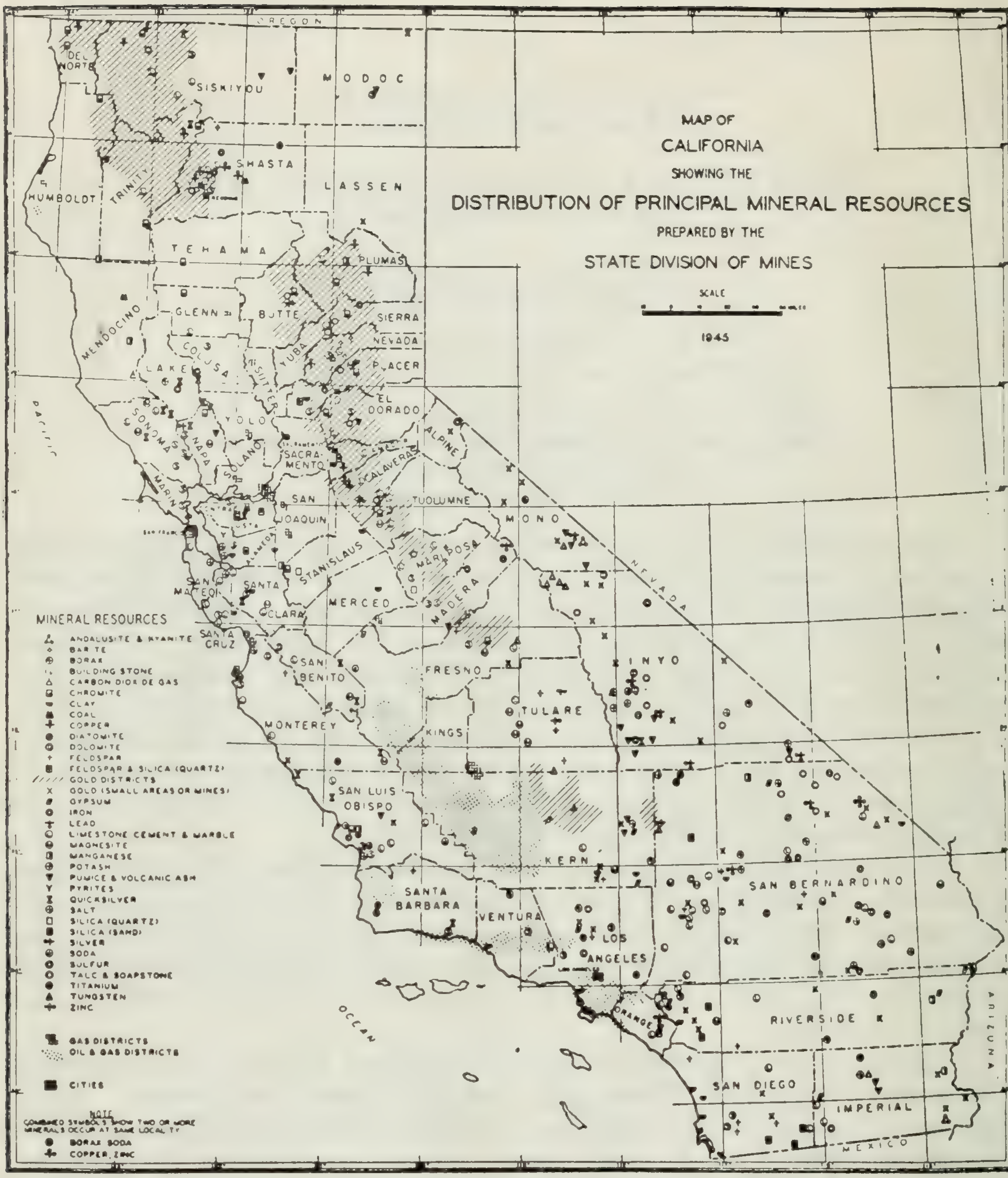
The Division of Mines maintains at its headquarters offices in San Francisco a technical library containing several thousand books and scientific journals on geology, mining, mineralogy, chemistry, metallurgy, and related subjects; a reading room containing periodicals devoted to the petroleum and mining industries, and newspapers from the mining centers of the state; exhibits of minerals, rocks, mine models, etc.; a service laboratory for the determination of California minerals; and a conference room with a mining engineer in attendance to serve the public and to sell publications of the Division. Publications are also sold at the Los Angeles and Sacramento district offices.

In addition to oral conferences in the offices of the Division of Mines, information concerning the mineral resources, mineral industry, geology, and mining operations of California is distributed to the public by means of publications, multigraph releases, and letters. Each letter of inquiry received by the Division is answered by the technical staff member best qualified to do so.

The principal publications of the Division of Mines are the quarterly **California Journal of Mines and Geology,** issued in January, April, July, and October of each year, and a series of **Bulletins. Mineral Information Service** is a monthly news release concerning the mineral resources and industry of California, designed to inform the public of discoveries, operations, markets, statistics, and new publications. It is distributed without cost upon request. A list of publications will also be sent free upon request.


MAP OF
CALIFORNIA
SHOWING THE
DISTRIBUTION OF PRINCIPAL MINERAL RESOURCES
PREPARED BY THE
STATE DIVISION OF MINES
SCALE
1945
OREGON
MODOC
SISKIYOU
DEL NORTE
SHASTA
LASSEN
HUMBOLDT
TRINITY
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
NEVADA
PLACER
MENDOCINO
COLUSA
LAKE
SUTTER
YUBA
EL DORADO
YOLO
SONOMA
NAPA
SOLANO
SACRAMENTO
ALPINE
CALAVERAS
MARIN
SAN JOAQUIN
TUOLUMNE
MONO
STANISLAUS
MARIPOSA
SAN MATEO
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
SAN BENITO
FRESNO
INYO
MONTEREY
KINGS
TULARE
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
PACIFIC
OCEAN
NEVADA
ARIZONA
MEXICO
MINERAL RESOURCES
ANDALUSITE & KYANITE
BARITE
BORAX
BUILDING STONE
CARBON DIOXIDE GAS
CHROMITE
CLAY
COAL
COPPER
DIATOMITE
DOLOMITE
FELDSPAR
FELDSPAR & SILICA (QUARTZ)
GOLD DISTRICTS
GOLD (SMALL AREAS OR MINES)
GYPSUM
IRON
LEAD
LIMESTONE CEMENT & MARBLE
MAGNESITE
MANGANESE
POTASH
PUMICE & VOLCANIC ASH
PYRITES
QUICKSILVER
SALT
SILICA (QUARTZ)
SILICA (SAND)
SILVER
SODA
SULFUR
TALC & SOAPSTONE
TITANIUM
TUNGSTEN
ZINC
GAS DISTRICTS
OIL & GAS DISTRICTS
CITIES
NOTE
COMBINED SYMBOLS SHOW TWO OR MORE MINERALS OCCUR AT SAME LOCALITY
BORAX SODA
COPPER, ZINC

CONTENTS

PLATES

UNUSUAL CONCRETIONS FROM TEMPLETON SAN LUIS OBISPO COUNTY, CALIFORNIA

By R. A. Crippen *

OUTLINE OF REPORT

Illustrations

ABSTRACT

Biconic concretions of agate and crystalline quartz, pseudomorphic after an unknown mineral, syngenetic in volcanic tuff of the Monterey formation, are found near Templeton, San Luis Obispo County, California.

INTRODUCTION

In the summer of 1947 concretions of unusual form and structure were received by the Division of Mines from Mr. C. K. Huff of Paso Robles, California, with request for explanation of their origin.

Greatly intrigued by the geological and chemical problems involved in their formation, the writer visited Mr. Huff to study more examples and their occurrence.

Specimens obtained from Mr. Huff, representative of the several hundred he has collected, were shown to a number of geologists familiar with the area, among whom were Drs. O. P. Jenkins,[1] N. L. Taliaferro,[2] A. O. Woodford,[3] P. D. Trask,[4] and Mr. C. W. Chesterman.[5] None had previously seen the concretions, but each offered helpful suggestions.

THE CONCRETIONS

Geologic Occurrence

The concretions have been found over an area of 2 or 3 square miles in cultivated fields south of Paso Robles near Templeton, on the west side of the Salinas River. The land, gently sloping to hilly, lacks outcrops and in general has a cobble-free mantle of soil. Adjacent to the home of Mr. Huff, however, is a dry creek bed with boulders and cobbles, and rising from it a low knoll plentifully covered with similar rocks which have been brought to the surface by cultivation. This area of an acre or so is prominent in the surrounding rock-free fields. From it has

* Supervising Geological Draftsman, California State Division of Mines. Manuscript submitted for publication March 10, 1948.
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[2] Department of Geological Sciences, University of California.
[3] Geology Department, Pomona College.
[4] Geologist, U. S. Geological Survey.
[5] Assistant Geologist, State Division of Mines.

come much of the concretionary material, as well as well-rounded igneous cobbles, sub-angular fragments of several types of jasper, and cobbles of quartzite and chalcedony. Also common are silicified wood fragments and large, partly silicified whale (?) bones. Fragments of the soft, light-colored Monterey shale, however, predominate. One specimen of concentrically banded contraction spheroids that have been described by N. L. Taliaferro [6] was also found. All of the cobbles apparently have been reworked and now form part of a remnant of either a conglomerate bed or of Recent river gravels.

N. L. Taliaferro, in an unpublished geologic map of the Templeton-Paso Robles region, indicates that the area in which the concretions have since been discovered lies astraddle the unconformity between the Monterey (upper middle Miocene) marine formation and the Paso Robles (Plio-Pleistocene) non-marine formation.

The Paso Robles formation, where seen in road cuts, is composed almost entirely of coarse, light-colored, siliceous shale fragments, evidently derived from the Monterey formation.

Rounded masses of similar appearing rock conceal most of the concretions but internally this matrix is hard, often silicified to opaline chert or jasper near the concretion. Sawn surfaces of the less silicified portions show scattered crystals, one millimeter and less in size, of feldspar and quartz in a fine groundmass of volcanic glass particles (determined with the petrographic microscope).

Thick beds of a similar volcanic tuff have been indicated by Taliaferro in exposures of the Monterey formation on Black Mountain about 11 miles west of Templeton.[7] The concretions, however, have not been found there.

Description

The symmetric biconic disc form characteristic of these concretions is unusual in that it is almost unknown in nature. Its lack of application by man as a design is equally notable. One instance is known to the writer; beads of this shape were made of stone by the Sumerians of ancient Babylon, about the 28th century B. C. Archaeologists called them "bicones".

The term "biconoid" seems preferable and is analogous to the words "discoid", "spheroid", and "ellipsoid" for concretionary shapes.

The average specimen is within the 3- to 6-inch diameter range, but many are larger. The maximum diameter seen by the writer was 10 inches, but a 14-inch specimen is reported by Mr. Huff.

Thickness is in proportion to diameter; angles of the diamond-shaped axial sections are quite consistently about $52\frac{1}{2}°$ and $127\frac{1}{2}°$.

Conic surfaces are broadly ridged and grooved in 15° to 20° sectors. These are sharply lined with what appear to be casts of acicular crystals which diverge fan-like from the conic apices and other points on both conic surfaces. The divergence is greater than radial angles and crystals seem to overlap other fan radii. This interference between adjoining bundles of crystals evidently produced the broad sectoral valleys and ridges.

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[6] Contraction phenomena in cherts: Geol. Soc. America Bull. vol. 45, pp. 189-232, 1934.

[7] Adelaide quadrangle, unpublished.

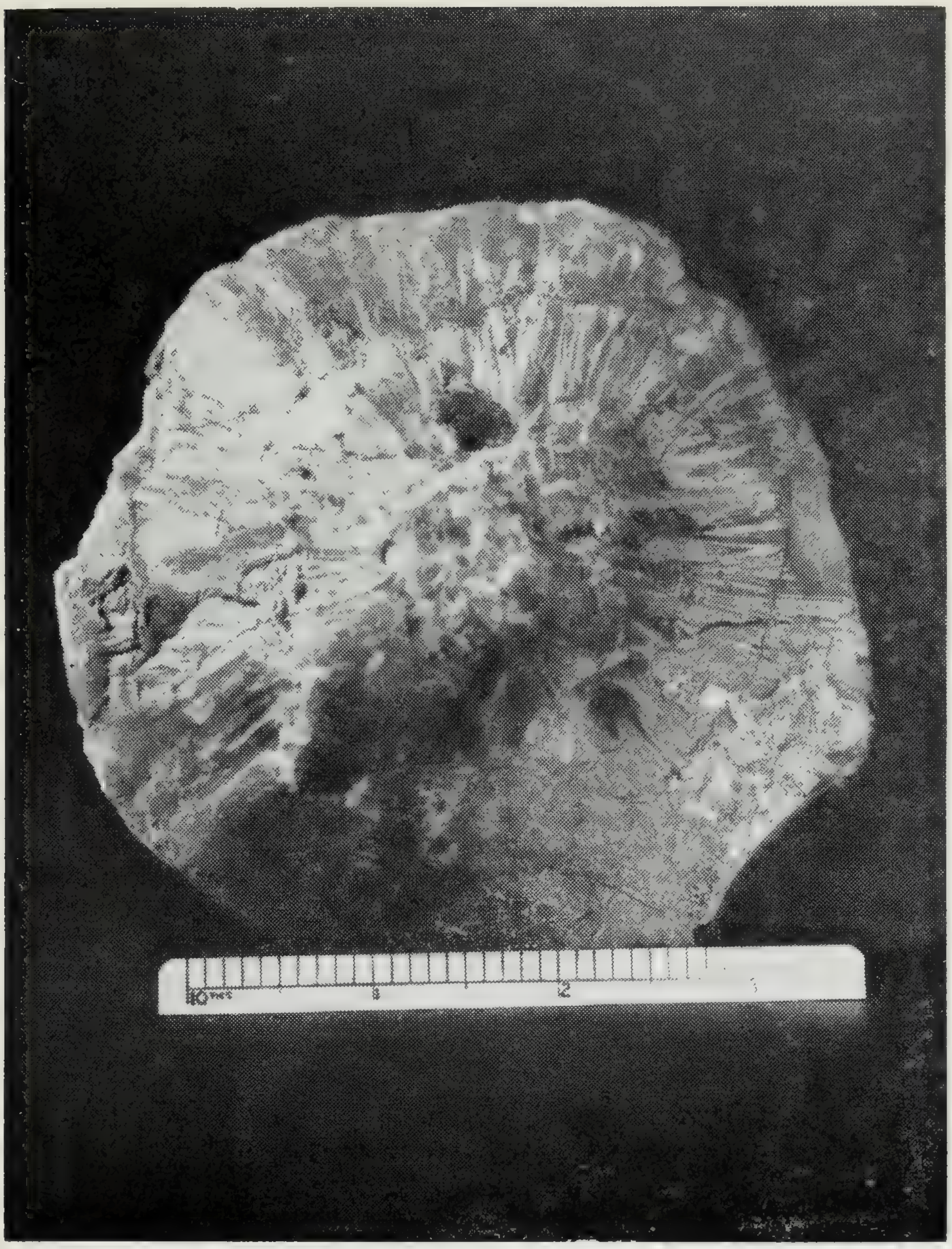

PHOTO SHOWING SURFACE OF A TYPICAL, WELL-FORMED BICONOID

2—88505

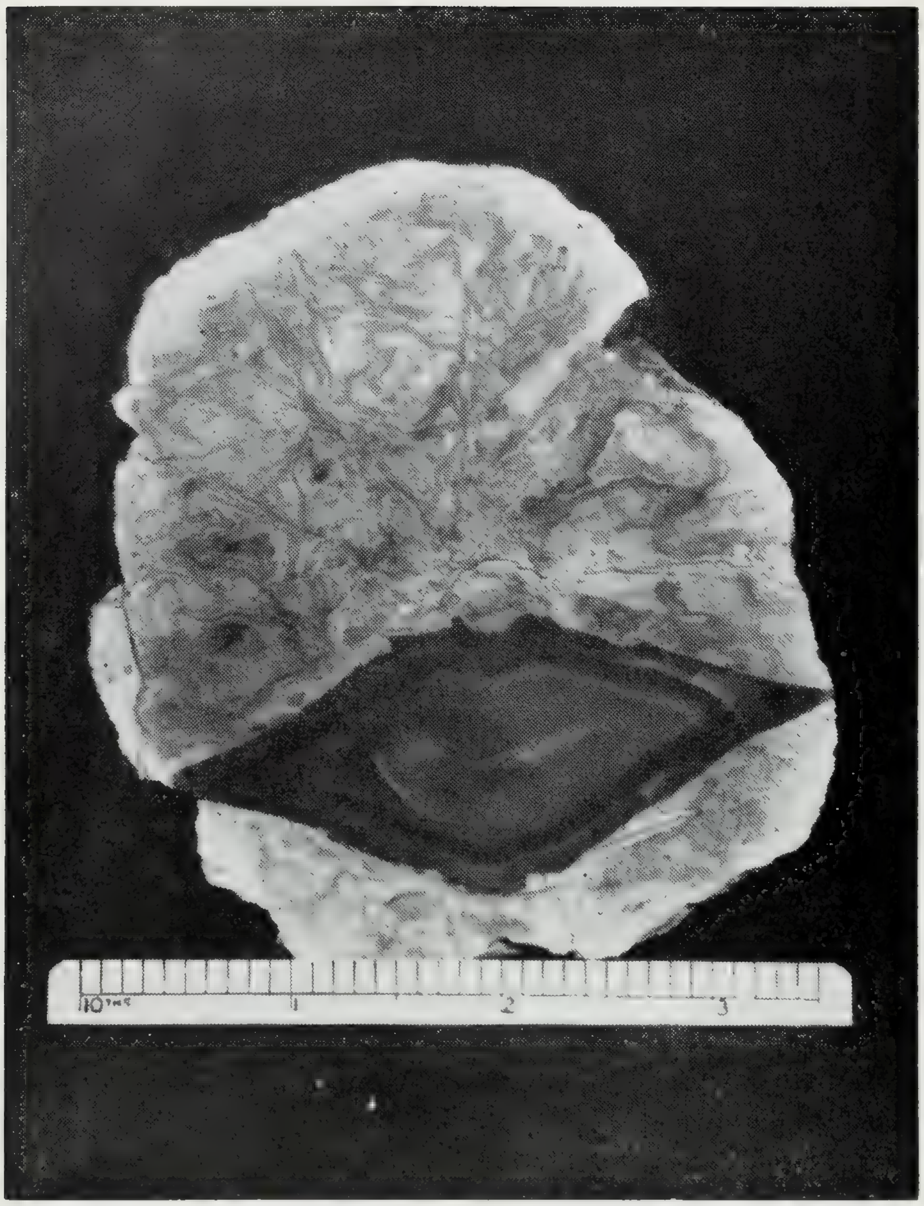

PHOTO SHOWING SECTION OF AGATE-FILLED BICONOID

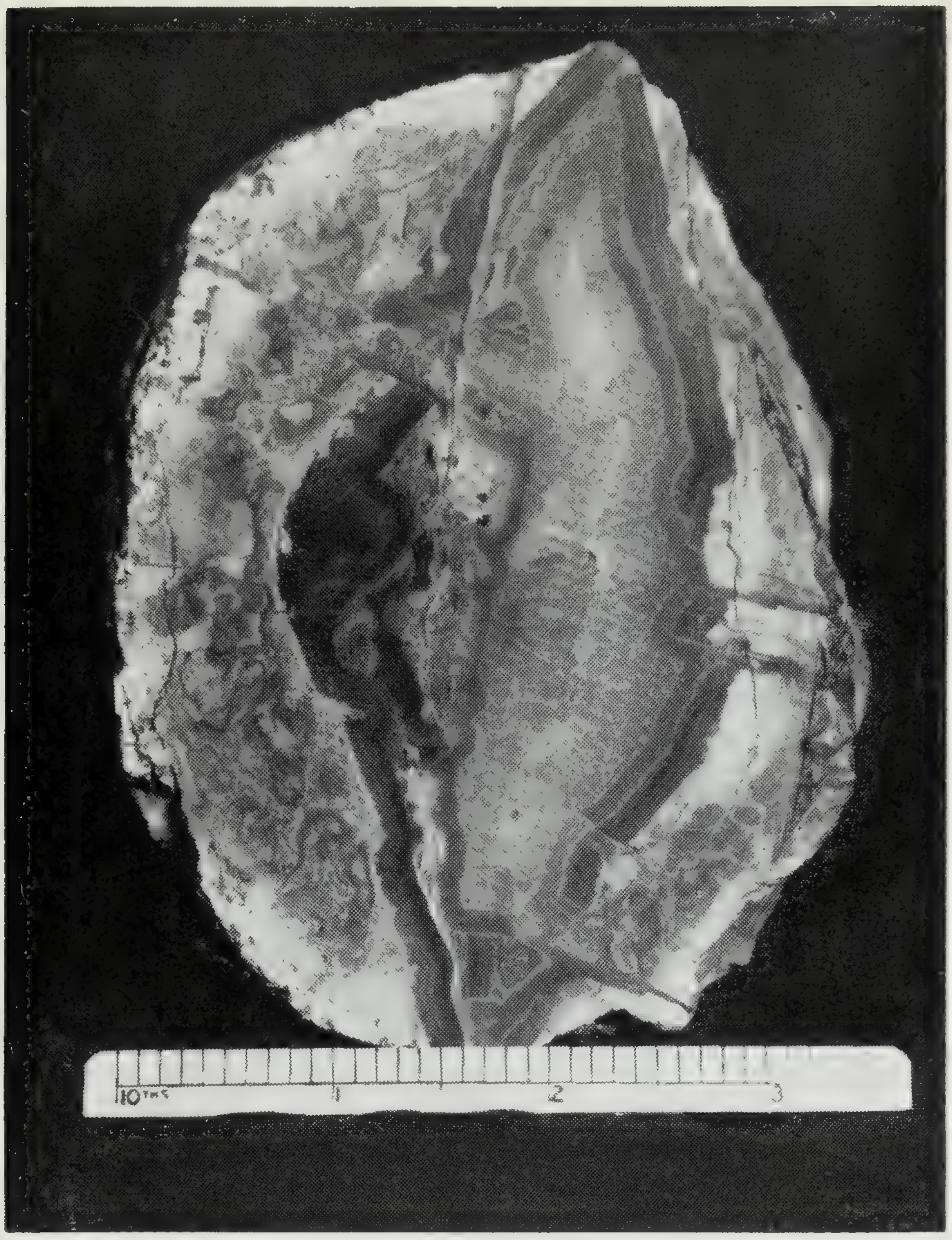

PHOTO SHOWING SECTION OF BICONOID WITH CRYSTALLINE QUARTZ CENTER AND THIN AGATE BANDS AT THE SURFACE

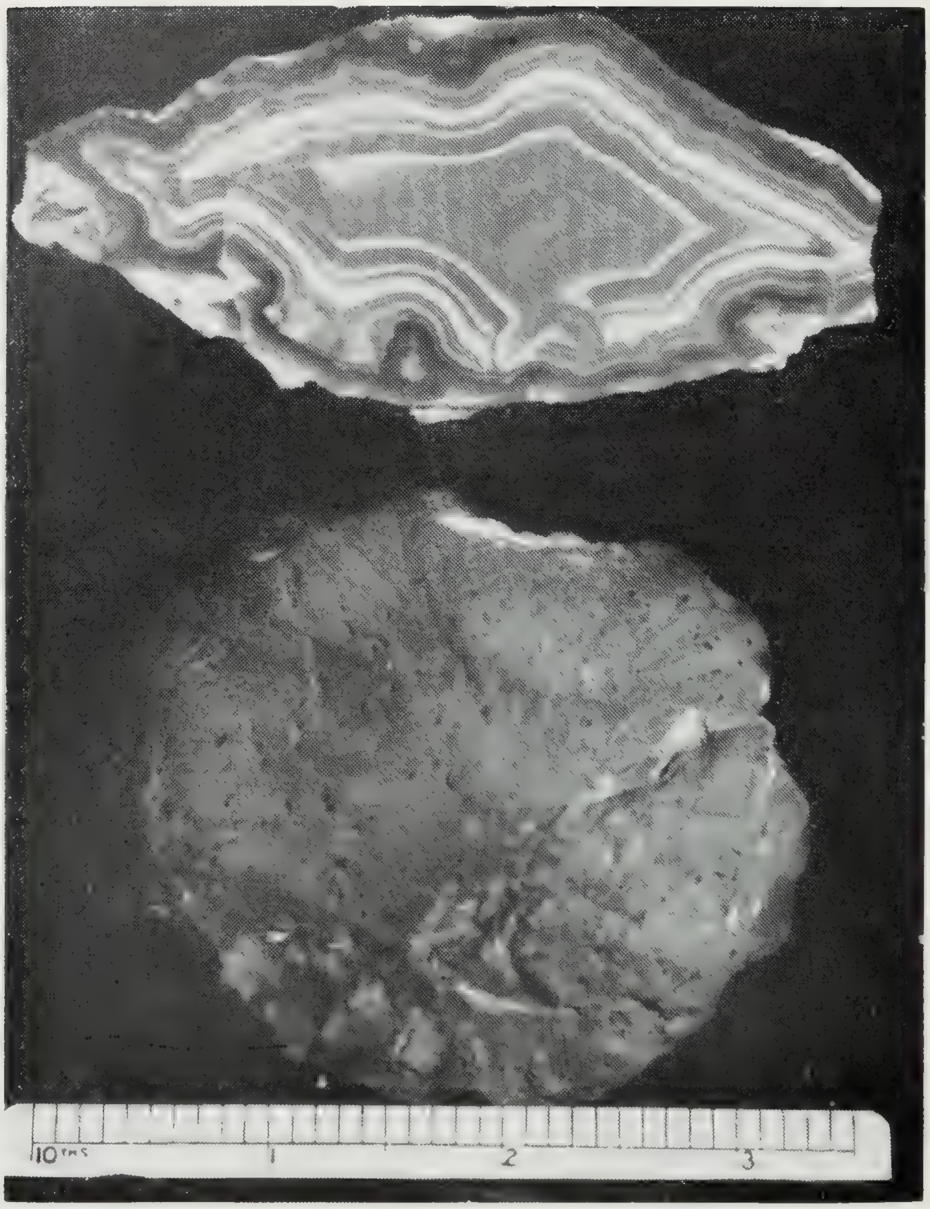

PHOTO SHOWING SURFACE OF SMALL BICONOID
AND SLICED SECTION CONTAINING
BANDED AGATE

Concretions having slickensided surfaces believed to have been caused by pressure of enclosing sediment are known,[8] but such an origin for the surface effect on the biconoids is hardly conceivable.

Other evidence of the original mineral is lacking, as banded agate has completely replaced the crystals. Internally the smaller biconoids are all agate, more or less well banded. Larger ones have colorless, intergrown crystalline quartz centers with but a quarter to half an inch of banded agate at the surfaces. Most of the agate is of dull shades of yellow, gray, and white.

Origin

The Templeton biconoids were probably syngenetic in their first crystallization. That is, their form was established by crystalline growth of a substance in the soft, accumulating volcanic tuff bed on the sea bottom.

There is a well established theory that syngenesis of concretions results from precipitation from solution of colloidal or gel-like material. This, when insufficient to form a stratum, coagulates and gathers in balls, which are buried under ensuing deposition. At some time before consolidation of the sediments, these balls, by dehydration or crystallization, become stable mineral concretions. Probable examples are the flint nodules in the chalk of England and France, and most calcium carbonate concretions in clay shales. Amorphous iron sulphide becomes pyrite or marcasite concretions in clay and coal beds.[9]

Concretions in tuff evidently have not been previously observed as the writer finds no mention of such occurrence. Mineral collectors of southern California are familiar, however, with the calcite balls which are so plentiful in bentonite beds east of Barstow. Bentonite is thought to be altered volcanic ash and it seems probable that the calcite balls are syngenetic concretions analogous to the Templeton ones. These radially crystallized spheroids of white calcite are conceivably of like origin, precipitated from carbonate solutions in a lake during volcanic eruption and ash deposition. This occurrence is the only one known to the writer which may throw some light on the original mineral of the Templeton biconoids. Volcanic activity was extensive during the middle Miocene and the Monterey formation is largely made up of highly siliceous sediments such as chert, diatomaceous shale, and pyroclastic material.

Although pure limestone is stated by M. N. Bramlette to be "remarkably rare", impure calcareous and dolomitic beds and concretions are described from several localities in Monterey shales.[10] The concretions are formless masses and in no way resemble the biconoids; their presence in the shales merely suggests that the original material of the Templeton concretions was calcium carbonate.

Compressive forces, causing folding and faulting, and elevation high above sea level, followed the volcanic period. In this new environment groundwater permeating the porous tuff became charged with silicic acid which removed the calcium carbonate. This epigenetic phase, with removal of the crystalline carbonate and refilling with silica gel, permitted fracturing and distortion of many biconoid molds. Small angular fragments of the tuff matrix caved into the gel; already formed agate

[8] Twenhofel, W. H., Treatise on sedimentation, 1926.
[9] Twenhofel, W. H., op. cit.
[10] Bramlette, M. N., The Monterey formation of California and the origin of its siliceous rocks: U. S. Geol. Survey Prof. Paper 212, 57 pp., 1946 [1947].

bands were displaced by small faults and subsequent bands of agate outlined the new configuration.

SUMMARY AND ACKNOWLEDGMENTS

The Templeton concretions present evidence of syngenetic origin in volcanic tuff. External features of form and crystal structure point to the growth of a crystallized mineral, believed to have been calcium carbonate, as calcite or aragonite, during deposition of the tuff. Removal of the calcium carbonate and filling by silica occurred following and perhaps during periods of faulting, folding, and elevation above sea level.

Rarity of the biconic form in nature is noted and the term ''biconoid'' is advanced for such solids.

Thanks are due to Mr. C. K. Huff for the gift of excellent specimens for study and for the Museum of the Division of Mines; also to L. A. Wright [11] and O. L. Bowen [12] for criticism of the manuscript.

[11] Associate Geologist, State Division of Mines.
[12] Junior Geologist, State Division of Mines.

QUICKSILVER DEPOSITS OF THE GUERNEVILLE DISTRICT SONOMA COUNTY, CALIFORNIA*

By W. Bradley Myers ** and Donald L. Everhart **
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

Illustrations

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication February 26, 1948.

** Geologist, Geological Survey, U. S. Department of the Interior.

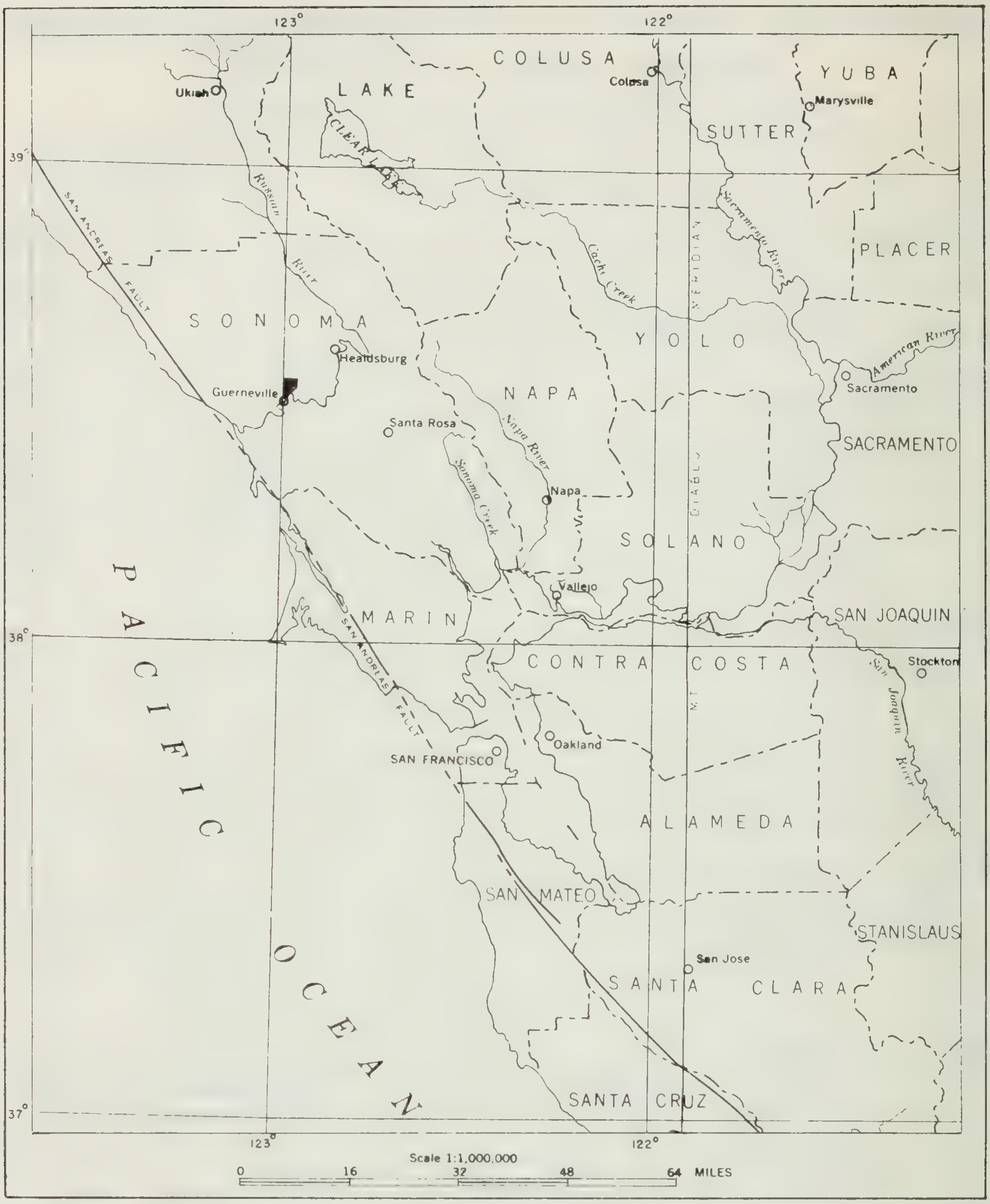

FIGURE 1. Index map of part of northern California, showing the location of the Guerneville mining district. Solid black represents area mapped.

ABSTRACT

The Guerneville district lies 4 miles northeast of Guerneville, Sonoma County, California, which is about 70 miles northwest of San Francisco. The district yielded 58,467 flasks of quicksilver up to the end of 1945, all of which came from the Great Eastern and Mount Jackson mines. The mines have been worked during three periods, from 1875 to 1906, from 1915 to 1919, and from 1934 to date.

The oldest rocks of the district belong to the Franciscan group, of Upper Jurassic (?) age, which here is chiefly represented by sandstone but includes some greenstone and a little chert and shale. Dike-like bodies, now consisting of serpentine, were intruded into the Franciscan rocks, principally along a fault zone trending west-northwest, on which there has been recurrent movement. Near the two mines the serpentine bodies are offset by northwest-trending faults of moderate displacement, which are offset in turn by northeast-trending faults of rather small displacement.

The Great Eastern-Mount Jackson quicksilver deposit is the only one in the district that is known to be commercially important. The ore shoots are steeply dipping pipes and tabular bodies, generally greatest in the vertical dimension. They are enclosed in silica-carbonate rock formed by hydrothermal alteration of serpentine. Most of the shoots are controlled by shearing and fracturing along post-serpentine, pre-alteration faults, striking in several directions, which cut the serpentine but are earlier than the alteration that produced the silica-carbonate rock. These faults formed conduits for ascending hydrothermal solutions, which altered the serpentine and deposited cinnabar in structurally favorable areas.

The only quicksilver mineral recognized in the district is cinnabar. It occurs chiefly in small grains disseminated throughout the silica-carbonate rock. In a few places cinnabar partly fills open fractures.

Sonoma Quicksilver Mines, Inc., the present operators of the Mount Jackson mine, estimated that on December 1, 1944 the reserves in that mine would almost certainly yield 6,040 flasks of quicksilver and might yield another 1,830 flasks.

In the Great Eastern mine the measured reserves are small, but there is a fair chance of finding new ore shoots in a block of silica-carbonate rock that probably lies adjacent to the lower workings.

INTRODUCTION

The Guerneville quicksilver district is in the California Coast Ranges, in the north-central part of Sonoma County (fig. 1). The Mount Jackson and Great Eastern mining properties, the only producers, lie in the northwest corner of sec. 16, T. 8 N., R. 10 W., M. D., in the Healdsburg quadrangle.

The mines are located on a prominent ledge of altered serpentine trending nearly due east, which has been deeply eroded by Fife Creek, a small tributary of the Russian River. The relief in the immediate vicinity is about 700 feet and the topography is moderately rugged (pl. 44).

The adit level of the Great Eastern mine, the portal of which is on the east side of Fife Creek, is here taken as the zero level for both mines; its altitude, as determined barometrically, is 415 feet above sea level. The two portals of the Mount Jackson mine are 67 feet lower than the Great Eastern adit and on the opposite side of Fife Creek (pl. 45).

The mines are reached by an excellent paved road from Guerneville, which lies to the southwest, 4 miles down Fife Creek. Guerneville is connected by State Route 12 with Santa Rosa, 18 miles to the east, and with San Francisco, about 70 miles to the southeast.

Becker [1] was the first to describe the general geology and the ore deposits of the district and to discuss its geologic history. Brief state-

[1] Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mon. 13, pp. 362-364, 1888.

ments concerning the geology of the mines have also been made in the following reports:

California State Mineralogist's Reports:

Number	*Initial page*	*Year*
VIII	633	1888
XII	371	1893–94
XIII	602	1895–96
XLV	347	1913–14

Bulletins of the California State Mining Bureau:

Number	*Initial page*	*Year*
27	108	1903
78	187	1918

During the summer and early autumn of 1942, the authors as members of the Geological Survey, United States Department of the Interior, mapped in detail an area of about 6 square miles surrounding the mines. This area includes the whole of secs. 16 and 17 and the greater parts of secs. 8, 9, 10, 15, 20, and 21, T. 8 N., R. 10 W., M. D., and is all in the Healdsburg quadrangle. The areal geology was plotted on photostatic enlargements, to a scale of 1,000 feet to the inch, of a part of the Healdsburg topographic sheet. A plane-table map of the topography and areal geology of the area immediately surrounding the mines was made on a scale of 40 feet to the inch. The accessible level workings of both mines were mapped on photostats of the same scale, made by reducing company maps of larger scales. In some places, notably on the —500-foot level, existing maps were augmented by tape and Brunton surveys.

The operators of the Great Eastern and the Mount Jackson mines were of great help both during the field work and in the preparation of this report. Among those especially helpful were Mr. Herbert F. Larsen, Mr. H. D. Tudor, and Mr. Stanley F. Wickam of Sonoma Quicksilver Mines, Inc., and Mr. Drexel E. Spalding, former superintendent, and Mr. John L. Desmond, superintendent of the Great Eastern mine. Mr. Jack Brown of Guerneville supplied valuable information concerning the history of the mines and the extent of workings and tenor of ore in those parts of the mines which are now flooded. A. C. Waters and E. B. Eckel of the Geological Survey offered many useful suggestions and criticisms, and the latter supplied guidance throughout the course of the work.

HISTORY AND PRODUCTION

The Great Eastern and Mount Jackson mines have been worked during three periods, the first beginning in 1875; and at the end of 1945 they had produced 58,467 flasks of quicksilver, which is more than two-thirds the total production of Sonoma County. From 1882 to 1894, when the price of quicksilver ranged between $29 and $52.50 per flask, these mines were the only producers in the county.

The first and longest period of mining extended from 1875 to 1906. Because of the rise of quicksilver prices during World War I, operations were carried on in the upper workings of the Great Eastern mine from May 1915 until early in 1919. The current period of mining began in the summer of 1934.

During the first few years of production, the two mines were worked independently and each operator reduced his own ore. From 1888 to 1906 the Mount Jackson property was leased by the Great Eastern operators, and ore from both mines was hoisted through the Great Eastern shaft and burned in the Great Eastern furnaces. By 1905 the main shaft of the Great Eastern mine had been sunk from the elevation of the zero level to a depth of 500 feet, and a winze extended 120 feet deeper; levels had been driven, also, at —70 feet, —140 feet, —220 feet, —360 feet, —500 feet, and —620 feet. Damage caused by the earthquake of April 18, 1906, led to the closing of the mines, and when they were reopened in May 1915 the lower levels were flooded. Until operations ceased in 1919, mining was carried on only above the hoist level in the Great Eastern mine.

From 1934 to 1939, several townspeople of Guerneville worked the adit level of the Mount Jackson mine intermittently and produced a few flasks of quicksilver. Sonoma Quicksilver Mines, Inc., gained control of the property in June 1940, and within a short time they built the plant that is still in use, began to dewater the mines, and sank the Mount Jackson underground shaft from the adit level. They started production on September 9, 1940. In May 1941 the Great Eastern property was acquired by Magee Mercury, Inc., which erected the present plant and began production on July 15, 1941. The Great Eastern mine was dewatered by pumping out the Mount Jackson mine, and its main shaft was cleaned out and retimbered to the —500-foot level.

The production of the two mines is shown in figure 2.

As the two mines were operated together during most of the first period of mining, the figures for 1875 to 1906 represent their combined production. During the second period, operations were restricted to the Great Eastern mine; for the latest period both separate and composite production figures are plotted.

GEOLOGY

General Outline

Most of the Guerneville district is underlain by rocks of the Upper Jurassic (?) Franciscan group; they are principally sandstone, though there is some interbedded shale and chert. Fault-bounded bodies of greenstone, also assigned to the Franciscan, are locally prominent but underlie less than 10 percent of the district. Small bodies of mica schist, apparently derived from sandstone of the Franciscan group, occur in many places along fault contacts of the greenstone bodies, and less commonly along other fault contacts (pl. 44).

Dike-like bodies of serpentine, somewhat younger than the Franciscan rocks, occur chiefly along a broad fault zone trending west-northwest in sandstone of the Franciscan group. They are altered in part to silica-carbonate rock, which contains nearly all the known ore shoots. Serpentine and its derivatives underlie less than 3 percent of the district (pl. 44).

After the Franciscan rocks had been uplifted, and probably after they had been deformed, high-angle faults of unknown magnitude, striking east, were formed along greenstone-sandstone contacts, especially in the northeastern part of the area. The schists along these contacts were probably developed at this time. Somewhat later, high-angle faults that

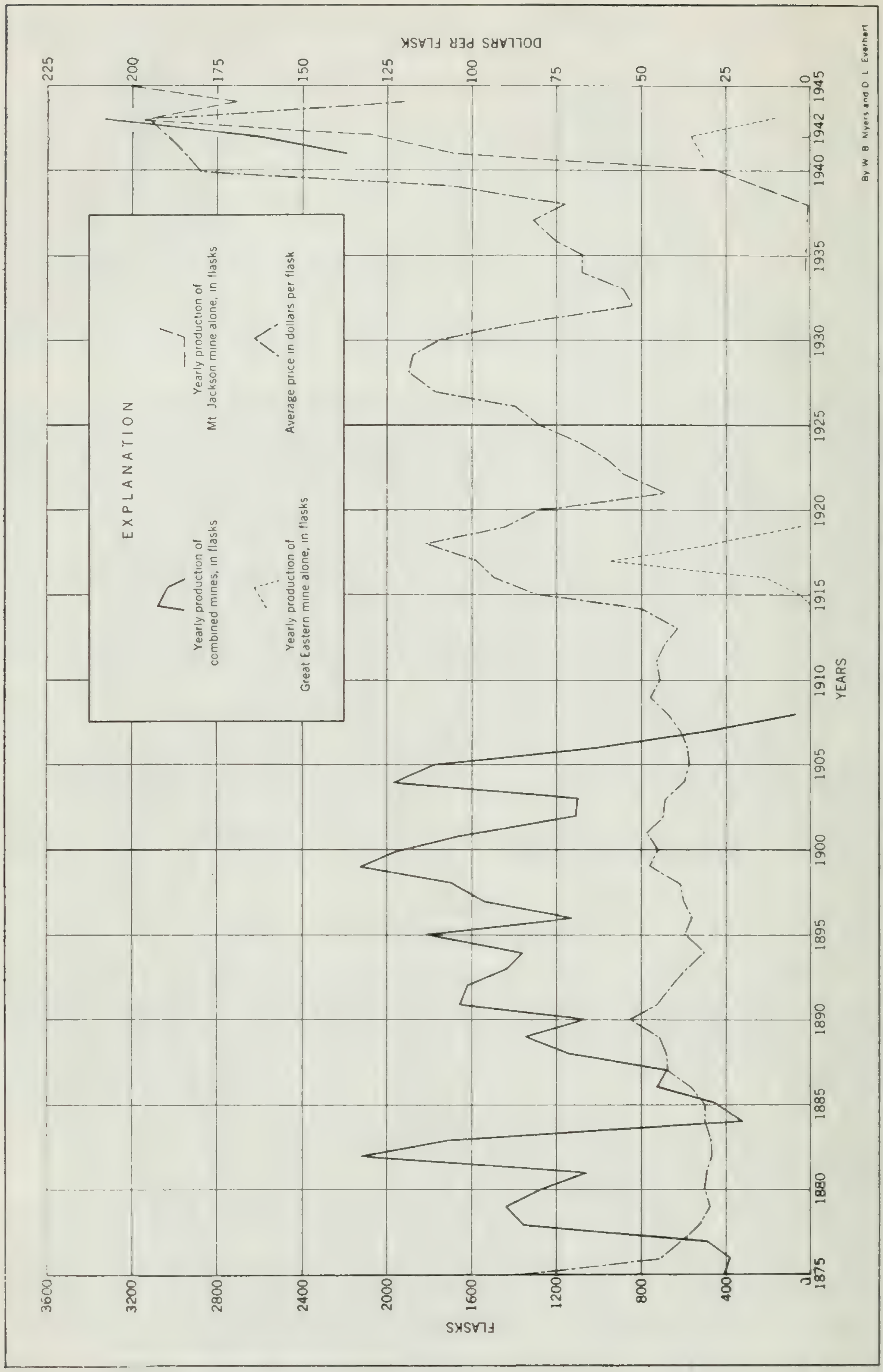

FIGURE 2. Production chart for the Great Eastern and Mount Jackson mines, 1875-1945.

strike nearly north were formed, along the most westerly of which there is a wide breccia zone. Subsequently another wide fault zone, trending about N. 55° W., was formed, and into this zone, probably during the Upper Jurassic, dike-like masses of either peridotite or its derivative serpentine were intruded. Such rocks were also intruded locally along certain of the east-trending faults and along at least one of the north-trending faults.

Most of the serpentine has been thoroughly sheared by movement that may have been either simultaneous with emplacement, or considerably later as a result of renewed faulting along the old fault zone.

In the vicinity of the mines, dike-like bodies of serpentine are cut and offset by faults that fall into two age groups. The faults of the older group strike about N. 30° W. and dip steeply to the northeast. With but one important exception, the hanging-wall block of these faults has dropped; the largest throw is at least 600 feet. The faults of the younger group strike northeast and are nearly vertical. Movement along these faults was probably nearly horizontal, and individual faults offset older structures as much as 70 feet.

Local renewal of movement along the hanging wall of a serpentine body in the vicinity of the mines sheared off projections formed by the earlier post-serpentine faulting.

The post-serpentine faulting was followed by widespread hydrothermal alteration of the serpentine, which throughout most of the district consisted of partial replacement of the rock by silica and dolomite. Alteration of a more intense kind took place adjacent to the faults exposed in the mines. The silica deposited in the intensely altered rock was dominantly quartz, whereas elsewhere in the district it consisted largely of opal and chalcedony. Minute fractures, possibly caused in part by a decrease in volume that may have resulted from the alteration, created open spaces in which veinlets consisting mainly of quartz were deposited. At nearly the same time, cinnabar and pyrite were precipitated in and upon the quartz throughout the rock and along the fractures. Subsequently a black amorphous hydrocarbon was deposited in vugs and open fractures.

Franciscan Group

Sedimentary Rocks. Sandstone of the Franciscan group underlies most of the mapped area. Coarse-grained varieties form bold outcrops in places, especially in the high ridges in the northwestern part of the district; commonly, however, the outcrops are subdued and rather deeply weathered. Almost without exception the sandstone is massive and fails to reveal any reliable evidence of bedding; only two bedding attitudes were observed in the district. Some of the sandstone is hydrothermally altered. No significant correlation of the alteration in the sandstone with known faults may be made throughout the mapped area but highly altered sandstone along the north bank of the Russian River at Rio Nido seems to be in a major fault zone similar to the one along which the Great Eastern and Mount Jackson mines lie (pl. 44).

Where it is fresh and unaltered, the sandstone is greenish gray to brownish gray. It is mostly equigranular and medium grained although coarse-grained and fine-grained varieties were found. The rock is highly feldspathic, containing both orthoclase and sodic plagioclase, and small quantities of biotite, epidote, and chlorite partly fill interstices between

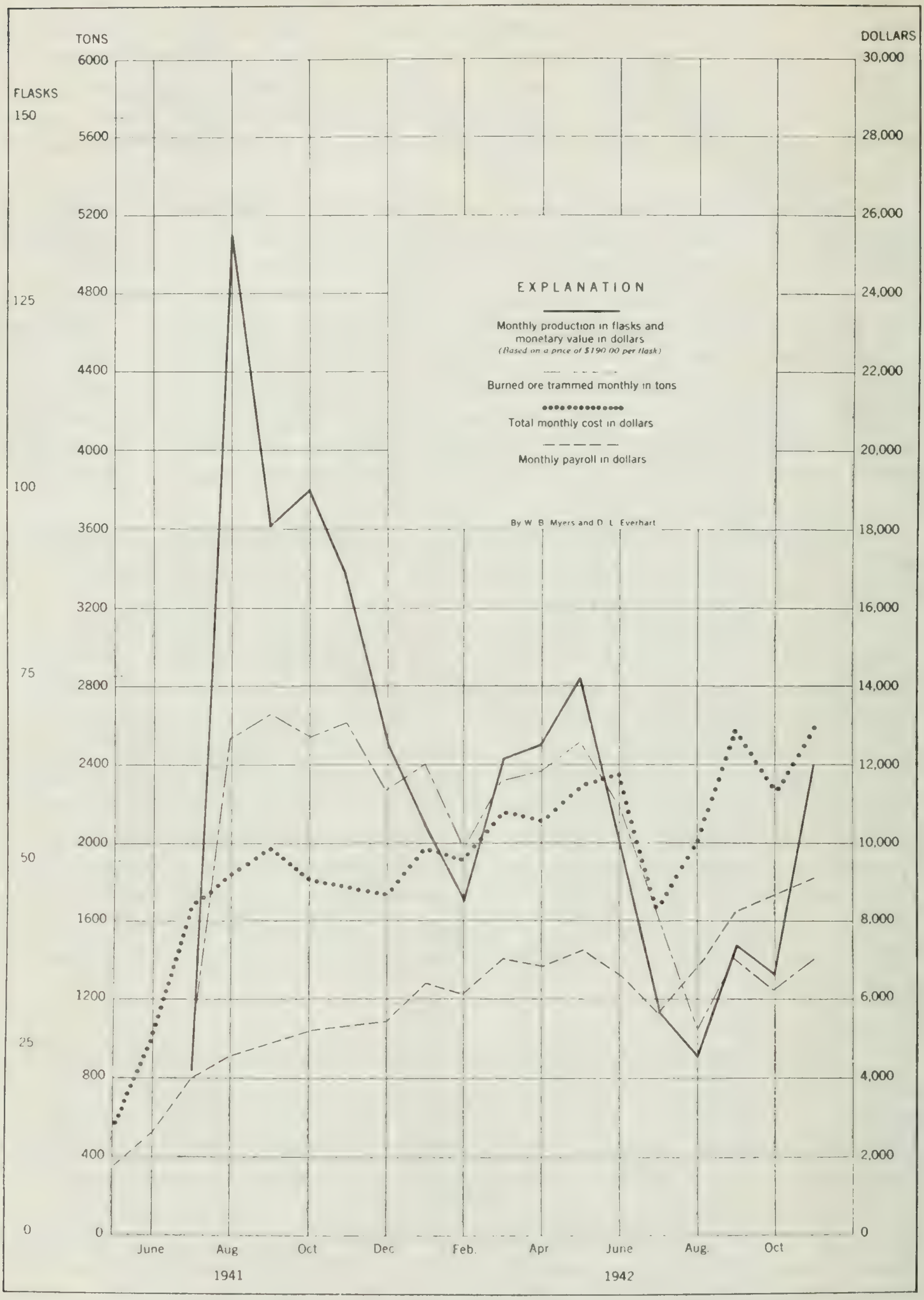

FIGURE 3. Graph showing production and costs of the Great Eastern mine, May 1941 to November 1942.

grains of quartz and feldspar. In contrast, much-altered sandstone is light-colored and the orthoclase is kaolinized.

Schistose rocks commonly occur in lens-shaped masses along contacts of the sandstone bodies with other rocks, notably greenstone and serpentine, and are thought to be derived from the feldspathic sandstone. They are rich in quartz and contain considerable mica, some feldspar, and a very little chlorite and garnet.

Boulders and irregular masses of fine-grained red, brown, and green massive chert are associated with the sandstone at various places. Radiolarian chert occurs in lenses in the sandstone and individual beds of it are 1 to 2 inches in thickness and locally contorted.

Greenstone. Igneous rocks that are somewhat metamorphosed and that contain abundant feldspar and ferromagnesian minerals have been mapped as greenstone. They are for the most part strongly weathered and occur in small outcrops, so that their detailed structural relationships are obscure, but it seems almost certain that they are largely bounded by faults.

The greenstones are largely altered basalt. The most common variety is a fine-grained dark-green to black rock which is characterized by well-developed jointing and a hackly fracture. One small body of fine-grained, black amygdaloidal basalt makes bold massive outcrops along the prominent ridge northeast of the mine. The rock is flinty in appearance, breaks with nearly conchoidal fracture, and is cut by late veins of quartz. As seen in thin section, the plagioclase of the basalts is albite and the rocks are considered to be spilitic basalt.

An unusual rock, shown on plate 45 as diabasic greenstone, occurs as inclusions in the serpentine masses that contain the ore bodies and as blocks in the adjacent fault breccia. Where fresh, it consists principally of plagioclase of intermediate composition and hornblende which may have been derived from pyroxene. In hand specimen, the rock appears to have a diabasic texture although the outlines of the crystals are somewhat ragged. Where the enclosing serpentine is hydrothermally altered, the greenstone itself is commonly altered to an aggregate of cream-colored clay consisting of kaolinite and montmorillonite.[2] Complete gradation from greenstone to clay was noted at two places in the mines; cores of hard greenstone were seen to be surrounded by zones in which the diabasic texture had been progressively obliterated by hydrothermal alteration.

Serpentine

Long, narrow bands of serpentine, derived from ultramafic rocks which were chiefly peridotite, trend westward and northwestward across the mapped area, and west of the district an irregular band of serpentine continues in a northwesterly direction for several miles. The present position of the serpentine bodies appears to have been controlled at least in part by faults which existed prior to the intrusion of these bodies. It is uncertain whether the bodies were emplaced as magma and serpentinized slightly after intrusion or whether they were emplaced as serpentine. Whatever the mode of intrusion, the serpentine bodies are now more or less thoroughly sheared. The strongest evidence favoring the intrusion of serpentine or its ultramafic antecedent into a pre-existing fault zone is negative: serpentine or ultramafic rock fragments are

[2] Determination by W. T. Schaller, U. S. Geological Survey.

absent in exposures of the fault breccia except for a few occurrences in the mine workings which appear to be localized along post-serpentine faults where dragged-in serpentine fragments might be expected. Where the serpentine has not been further altered by later mineralizing solutions it is commonly soft and crumbly, greasy in luster, and light pistachio-green to dark-green in color.

The Great Eastern-Mount Jackson ore deposit occupies parts of a composite serpentine body which is traceable on the surface for about 3,000 feet and which ranges from 50 to more than 200 feet in width (pl. 44). The center of the ore deposit is about midway between the ends of this body. In the immediate vicinity of the mines, the serpentine body splits into two adjacent tabular bodies, the main one being to the south and the smaller body to the north.

The split character of the serpentine body is not as obvious on the surface as in most of the underground workings of the mines. The main serpentine body widens in the lower levels of the mine, and on the —500-foot level there is some evidence that the smaller serpentine mass wedges out downward. Underground the two masses are separated in most places by a persistent septum of fault breccia from a few feet to as much as 60 feet in width. This septum is not exposed continuously on the surface. West of Fife Creek and above the zero level the two serpentine bodies coalesce. A small wedge-shaped mass of altered serpentine to the south of the larger serpentine body, exposed near the portal of the Great Eastern adit level, is included as part of the larger body to simplify description.

Silica-Carbonate Rock

The serpentine has been altered in places to silica-carbonate rock, which here as in many other quicksilver mines of California forms the gangue of most of the ore. All stages in the alteration of the serpentine seem to be represented, but two main types of silica-carbonate rock may be recognized. The more widespread is opaline silica-carbonate rock, which occurs in more or less tabular bodies replacing serpentine masses. This rock usually preserves the original texture of the serpentine, and it is very brittle, breaking with a sub-conchoidal fracture. It contains no commercial quantities of cinnabar. The second type, which contains almost all the known ore shoots in the district and which represents a more intense stage of alteration, is designated as coarsely granular silica-carbonate rock, its texture being like that of marble. In this rock the carbonates predominate, and the silica, though partly opal, is mostly clear glassy quartz. The coarsely granular silica-carbonate rock is found only in the immediate vicinity of the mines and in the mine workings. It is further described in connection with the mineralogy of the ore deposits.

Fault Breccia

Extensive faulting in the Guerneville district has produced zones of fault breccia of considerable thickness which are well exposed in the mine workings and in the surface croppings near them. Where it is unaltered, the fault breccia is made up chiefly of streaked and lenticular fragments of Franciscan rocks imbedded in extremely fine-grained, greasy looking, highly sheared black gouge. The fragments, which consist mainly of sandstone but include considerable amounts of shale and

greenstone, range up to at least 14 feet in diameter. Serpentine is locally present in the breccia, but it appears to be confined to post-serpentine faults. Locally the breccia has been more or less intensely altered. This alteration consisted of replacement by dolomite and fine-grained quartz and the resultant rock is dark gray to black in color and is homogeneous. In general it forms irregular shells, commonly a score of feet in thickness, around the silica-carbonate bodies in the mine, but the breccia seems to have been much less sensitive to the altering solutions than was serpentine. The altered fault breccia in the mine workings is surprisingly strong and only locally requires timbering.

Structure

Faults of several different ages and trends, all characterized by steep dips, are the prominent structural features of the Guerneville district. The most important of these is a west-northwest trending broad fault zone with a steep northeast dip; movement on this zone probably began before the end of Jurassic time and has certainly recurred at least once since that time. The importance of folds in the district is unknown.

Folds

The lack of observable bedding attitudes in the sedimentary rocks of the district effectively prevents any analysis of the folds which probably are present in the district. Only two observations of bedding were noted in the entire area, one in the adit of the Mount Jackson mine (pl. 46), the other just at the northern edge of the main fault zone and a short distance west of that mine. At both localities the beds have a west-northwest strike and a dip of 70° NE., and therefore are essentially parallel to the fault zone. The direction of the tops of the beds is unknown; moreover, the proximity of both localities to the fault zone prevents the use of these attitudes as any indication of regional structure.

The trends of greenstone bodies, on the assumption that these bodies represent original flows, at least in part, are in general concordant with the trends of the chert lenses (pl. 44). From these trends it seems probable that any folds northeast of the main fault zone have approximately east-west axes. Southwest of the fault zone in the western part of the district similar evidence suggests that trends of possible folds may be east-northeasterly. Throughout the district the contacts of chert and greenstone bodies with the sandstone suggest steep dips.

Faults[3]

Faulting of the rocks in the Guerneville district is complex. Five groups of faults that differ in age have been recognized, four of which have been seen in the mine workings. The first three are older than the serpentine intrusions; the last two are younger. The five groups will be described briefly in chronological order and then individual faults of economic importance will be discussed.

Group 1. The faults of the oldest group strike approximately eastward and seem for the most part to be nearly vertical; the direction of movement on them is unknown. They are best represented in the northeastern part of the area mapped, where they form the northern and

[3] In this report the dislocations caused by faulting are described as follows: *Displacement* is a general term describing any movement of one fault block relative to an adjacent block; *Offset* of a contact is the horizontal displacement measured at right angles to the contact; *Throw* is the vertical displacement of a point.

southern contacts of some of the greenstone bodies shown in plate 44. These faults are thought to represent bedding-plane slips, possibly on a large scale. The silica-carbonate rock of the Great Eastern mine was derived from serpentine that was probably injected into a fault zone of this group. A similar postulated fault zone contains the line of discontinuous serpentine and silica-carbonate blocks that may be traced for nearly a mile eastward from a point a quarter of a mile northeast of the Great Eastern mine.

Group 2. The faults of the second group are not encountered in the mines. They trend north, and are nearly vertical. The direction of movement on these faults was probably for the most part down the dip. Fourteen faults of this group were mapped within a distance of little more than 1 mile, where they cut the east-trending greenstone bands into small blocks. The greenstone contacts are offset from a few tens of feet to about 1,100 feet.

Group 3. The third group of pre-serpentine faults, which strike N. 50°-75° W. and dip 55°-70° NE., constitute the most persistent and economically important fault zone in the district. This zone averages a quarter of a mile in width and appears to extend across the entire mapped area. In some places, particularly near the mines, it is conspicuously marked for a considerable portion of its width by intensely sheared sandstone-shale breccias containing blocks of greenstone, chert, and schist, but in other places, especially where it is wholly within sandstone of the Franciscan group, it cannot be traced. It is possible that the extensive development of fault breccia in the vicinity of the mines is due in part to a low-angle intersection of a lens or zone of shale by the fault zone.

Group 4. The fourth group of faults, which are post-serpentine but pre-mineralization in age, were mapped largely within the Great Eastern and Mount Jackson mines. On the average, these faults strike about N. 30° W. and dip 70° NE. and with two exceptions (mentioned in the discussion of individual faults below) they are normal. A few striations on the slickensided walls of some of the faults indicate that the last movement, at least, on those faults was nearly down the dip. The economic significance of some of the important faults in this group is discussed in detail below.

Group 5. In the mines the faults of group 4 are offset by those of group 5, which are pre-mineralization faults of small to moderate displacement. On the average these later faults trend about N. 50° E. and stand nearly vertical, though individual faults may dip as low as 60° in either direction. The movement on them is thought to have been nearly horizontal. They commonly have a branching habit: a single fracture, with a relatively large offset on one level, may be represented on another level by several splits, one of which is likely to have a much larger throw than the others. These splits range in strike from a few degrees east of north to about N. 70° E., but the dominant fractures consistently strike about N. 50° E.

The Role of Individual Faults. Faults of groups 3, 4, and 5 are the most important in interpreting the structural control of the quicksilver deposits. The faults of group 1 have exerted control only as possible guides for serpentine intrusions. Similarly, the faults of the second group are not directly related to the deposits, although the west-

ernmost of them (pl. 44) may have had an important influence on the post-serpentine faults, which appear to be confined to the immediate vicinity of the mines.

The quicksilver mines lie on the northern margin of the fault zone comprising group 3 at or near its intersection with one of the older, east-trending fault zones of group 1. In the upper levels of the Great Eastern mine the fault-controlled silica-carbonate body strikes nearly due east and is almost vertical, but in the lower levels of this mine and in the Mount Jackson mine to the west it strikes about N. 70° W. and dips 55°-70° NE. This change in attitude, associated as it is with an unusual amount of shearing and brecciation, is believed to have resulted mainly from the intersection of the east-trending fault zone of group 1 by the fault zone of group 3, which has a more northwesterly trend.

The fourth group contains a number of individual faults which were mapped in several levels throughout the mines and are considered important because they offset the serpentine and hence controlled the positions of the silica-carbonate bodies and therefore have a direct bearing on exploration of the ore bodies.[4]

The most important fault of this fourth group, labelled I on the maps, offsets the south contact of the main serpentine body at the mines a little more than 200 feet, and if the movement was straight down dip, the throw of this fault is at least 600 feet. This fault is marked on the surface by a prominent scarp of silica-carbonate rock. It forms the western boundary of the group of related oreshoots worked in both of the mines, and the intensely altered serpentine in the mines is entirely bounded on the west by the breccia of this fault. Where exposed in the mine workings the fault steepens downward, its dip being 68° near the surface and 82° between the —360-foot level and the —500-foot level.

Fault II is parallel to fault I and lies a short distance east of it. The narrow block between the two is down-dropped; in the southern part of the workings its width is 14 to 25 feet. In this down-dropped block the footwall of the main serpentine body is offset to the south by an amount that ranges, where measured in the mine, from 25 to 80 feet.

Fault III of the fourth group, though visible in the ground of the Mount Jackson mine, is best exposed in the workings of the Great Eastern mine, in the future life of which it may prove to be of much importance. As is common with the faults of this group, the south contact of the main serpentine body is offset relatively southward in the hanging-wall or eastern block. The throw of fault III is believed to be about 200 feet, and on the —220-foot level (see plate 47) the total offset caused by this fault and five small ones near by, presumably in the same group, is more than 70 feet. Between the —220-foot level and the —500-foot level all the workings intersecting the projection of fault III are in silica-carbonate rock, which was formed after the conclu-

[4] The hydrothermal alteration of the serpentine bodies to silica-carbonate rock and the less complete replacement of the adjacent fault breccia by carbonate and fine-grained quartz has largely obliterated the evidence of pre-alteration faults except where different rock types are faulted together. In some instances post-alteration fault movement or fracturing or the presence of a high-grade ore streak allows the tracing of a fault through a homogeneous body of altered fault breccia or silica-carbonate rock. In most places, however, the courses of the faults shown on plates 46 through 50, have been inferred between or beyond localities where different rocks have been brought in contact or where attitudes are indicated. Thus the location and even the existence of certain of the faults on a given level of the mine workings may be completely inferential. Nevertheless, a consideration of the geology of all of the workings in three dimensions leads the writers to the belief in the existence and continuity of these faults.

sion of all major fault movement, and there the fault has not been recognized. A fault of similar attitude and believed to be the downward extension of fault III is well exposed, however, for a short distance in a stope in the northeastern part of the —500-foot level. There the breccia in the hanging-wall is brought into contact with intensely altered serpentine in the footwall. Determination of the displacement on the fault on the —500-foot level is difficult because of relatively large later movements on faults of group 5, but after comparing the maps of the —500- and —220-foot levels and studying the vertical projections, it was concluded that the footwall of the main serpentine body was offset at least 60 feet. It is believed, therefore, that fault breccia caving into an inaccessible south-trending cross-cut in the southeastern part of the —500-foot level (coordinates 540 N., 145 E.) is not the true footwall but part of the septum dividing the main or southern body of serpentine from the less extensive northern body, and that the silica-carbonate rock prospected east of fault III was derived from the serpentine of the northern body.

If this reasoning is correct, there should be a segment of the main serpentine body adjacent to the deeper workings of the Great Eastern mine that does not appear to have been prospected below the inaccessible —260-foot stope level.

The tabular ore shoot crossing the Mount Jackson-Great Eastern end line and stoped from the —270-foot level to the —415-foot level is apparently controlled by a fault from group 4, labelled IV on the maps and sections. Good exposures of a footwall fault striking N. 45°-55° W. and dipping 50°-55° N. are seen in the stope between the —360- and —415-foot levels. The displacement is unknown, because silica-carbonate rock forms both the footwall and hanging-wall blocks, but probably the hanging wall was dropped a short distance. Poorly developed mullions and the striae on slickensides, which are partly later than the mineralization, indicate that the last movement was directly down the dip. The fault has not been exposed on the —500-foot level, and if it occurs there it must be somewhat east of the present workings.

A fault striking about N. 75° W. and dipping 45°-50° NE. is well exposed on the —70-foot level of the Great Eastern mine (see plate 46), where it locally forms the southwest contact of the main or southern serpentine body. This fault, labelled X on the detailed maps and sections, is thought to be slightly later than the northwest-trending faults described in the preceding paragraphs. A higher fault exposed in a working stope above the —70-foot level is probably a nearly parallel branch of fault X. The hanging walls of both these branches appear to have moved relatively up the dip, that of the lower branch about 35 feet and that of the higher about 50 feet. Fault X apparently ends against the northwest-trending fault III, although their junction is not exposed in the workings. Below the —70-foot level, fault X forms the footwall of the filled stope between the —220-foot level and the —140-foot level, and it probably offsets the upward extension of fault IV, which is believed to control the ore in the large stope between the —415- and the —270-foot levels. Faults X and IV differ in attitude, both in strike and dip, by more than 15°, and fault X is apparently a reverse fault whereas fault IV is probably normal.

In the Mount Jackson property, the faults of group 5 have displaced the northwestern block to the northeast in each case, but the contrary

is true in the Great Eastern mine, so that a compound central block has been displaced southwestward relative to the blocks on either side. These conditions may be observed underground below the —360-foot level and are especially well marked on the —500-foot level, although fault B, forming the northwestern side of the southeasternmost fault block, was not certainly recognized. Fault A, which bounds the block on the southeast, is exposed at two places on the —500-foot level. The southeastern set of faults was not recognized between the —67- and —220-foot levels, though it was seen at depth and on the surface.

The offset of the footwall of the main serpentine body by fault A dies out upward; it is more than 70 feet on the —500-foot level, totals about 40 feet for the two branches of the fault on the —360-foot level, and apparently dies out before reaching the —220-foot level. This downward increase in offset results in a downward steepening of the footwall of the serpentine in the northwestern block, from 55° NE. at the surface to 86° NE. at the —500-foot level. In the block southeast of fault A the dip of the footwall of the serpentine in the lower part of the mine is more uniform than that in the northwestern block; the dip between the exposures on the —360-foot level and those on the —500-foot level being 67° NE. The lower part of the northwestern block thus appears to have been partially rotated by flexure of that block. In both blocks the hanging wall has a flatter dip at any given level than the footwall, showing that the serpentine mass thickens downward.

The offsets of many of the faults of group 5 tend to compensate the offsets of the earlier northwest-trending cross-faults, so that a small net offset may result from the cancelling effect of several offsets of rather large magnitude. Earlier fault contacts, also, have locally been dragged by subsequent movements into the attitudes of later faults, and it is easy to mistake some of the intersections of dragged faults with later faults for rolls in a single fault surface. These complications make it difficult to interpret the structural geology of the mines in detail.

ORE DEPOSITS

The only quicksilver deposit in the Guerneville district that is known to be commercially important is the one exposed in the workings of the Mount Jackson and Great Eastern mines, and the only quicksilver mineral recognized in the district is cinnabar. Metallic minerals associated with cinnabar, all in small amount, include residual magnetic and chromite and later magnetite and pyrite. The gangue consists mainly of silica-carbonate rock, though a few small ore shoots have been discovered in sandstone or in fault breccia adjacent to silica-carbonate rock. A small to moderate proportion of an amorphous black hydrocarbon generally accompanies the ore.

The ore shoots are steeply dipping pipes and tabular lodes, generally largest in the vertical dimension, enclosed in silica-carbonate rock derived from serpentine by hydrothermal alteration. The shoots are commonly controlled by shearing and fracturing along several groups of faults, which displaced the tabular bodies of serpentine before its alteration to silica-carbonate rock.

Mineralogy

Silica-carbonate rock makes up the gangue of practically all the quicksilver ore, although a few small ore shoots have been discovered in the sandstone or fault breccia adjacent to silica-carbonate rock bodies.

The character of the silica-carbonate rock depends on the degree of alteration of the original serpentine. Slightly altered serpentine is fine grained and preserves the sheared and streaked texture of the original rock, but differs in hardness and luster. Where the alteration has been restricted to slight carbonatization, the green color has been retained and the rock has a hardness about equal to that of dolomite. Opaline silica-carbonate rock, which in general tends to preserve the serpentine texture, is characterized by the high luster of opal and by its hardness and brittleness. Thoroughly altered silica-carbonate rock displays very few remnants of sheared serpentine texture and is light to dark gray in color. It is homogeneous and medium grained, and it typically has a sugary appearance. Late veins of carbonate and clear, glassy quartz commonly fill fractures cutting the ore-bearing rock. The silica-carbonate rock is massive, homogeneous, and hard, and it tends to break with a blocky fracture. These properties facilitate mining, for large stopes can be mined without timbering and floor pillars need to be only 4 or 5 feet thick.

At certain places, both on the surface and at depth in the mines, alteration has rendered the silica-carbonate rock soft, crumbly, and ocherous. Some of the richest pockets of ore have been discovered in this porous rock. The cause of this alteration is uncertain. It may be supergene, caused by percolating surface waters which, in the more permeable locations, oxidized the pyrite and leached the silica-carbonate rock. The common coincidence of ocherous alteration and high-grade ore is probably a result, therefore, of the tendency of both ascending and descending solutions to follow the most permeable routes.

Thin sections were prepared from a series of nine specimens of silica-carbonate rock from the mine workings and the mineralized outcrop on the surface. In collecting them, an attempt was made to show progressive alteration from the original serpentine to ore-bearing, coarsely granular silica-carbonate rocks. The minerals identified in the thin sections of these rocks are listed in the following table:

Minerals of the silica-carbonate rock

Name	Composition	Percent
Metallic minerals		
Cinnabar	Red mercuric sulfide (HgS)	Up to 4
Pyrite	Ferric sulfide (FeS_2)	1
Magnetite	Ferrous and ferric oxide ($FeO.Fe_2O_3$)	1–3
Chromite	Ferrous chromate ($FeO.Cr_2O_3$)	Traces
Non-metallic minerals		
Serpentine minerals	Hydrous magnesium silicate ($H_4Mg_3Si_2O_9$)	Up to 20
Ferroan dolomite*	Mixed carbonates ($CaCO_3$. (Mg, Fe) CO_3)	60–70
Opal	Hydrous silica ($SiO_2.nH_2O$)	25–40
Chalcedony	Silica (SiO_2)	
Quartz	Silica (SiO_2)	
"Limonite"	Various ferric oxides and hydroxides	1
Hydrothermal clays	Hydrous aluminum silicates	Less than 1
Hydrocarbons	C_nH_{2n+2}	Up to 2

* Identification of the carbonates is based on microscopic examination of powders immersed in oils and the treatment of polished surfaces with dilute hydrochloric acid.

The most widespread alteration was the replacement of the serpentine by carbonates (fig. 4); those carbonates that were tested by the oil-immersion method have maximum index values (N_o) values ranging from 1.690 to 1.705, the most common value being about 1.70. This index

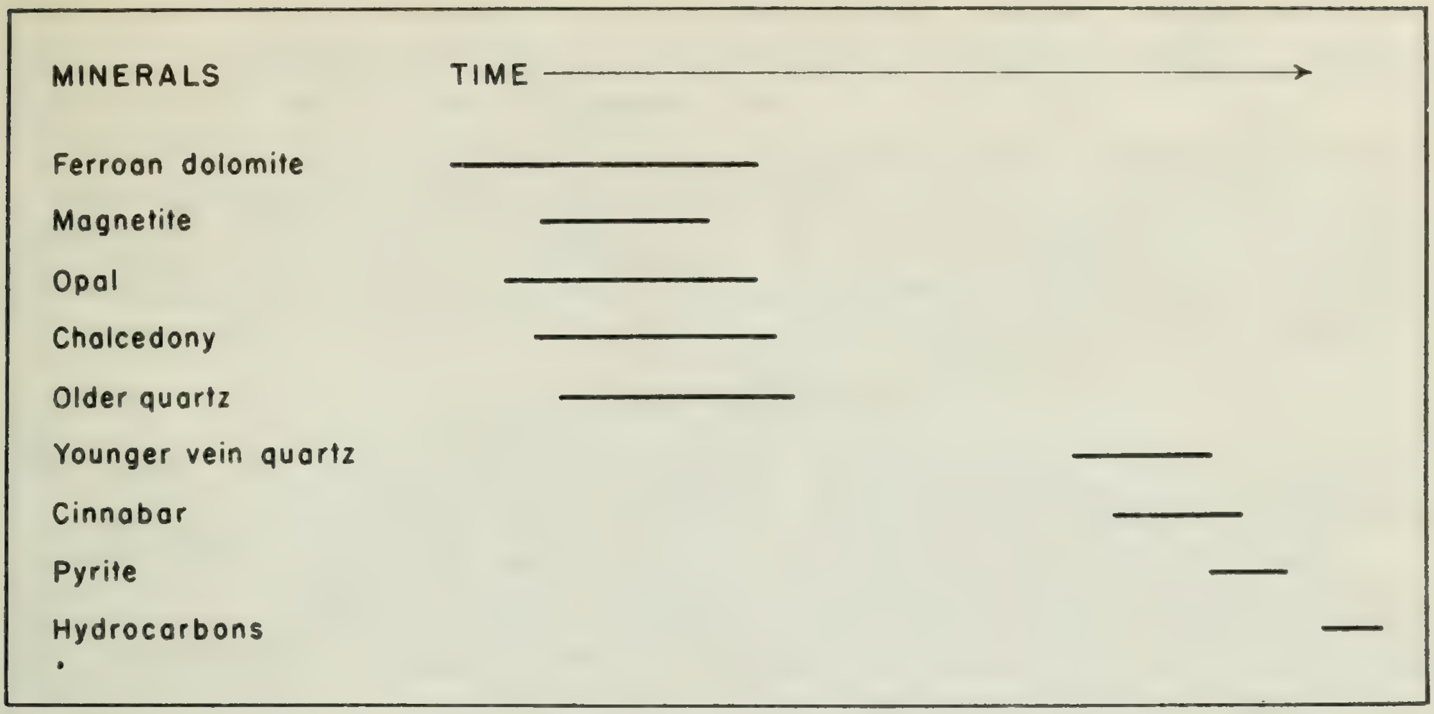

FIGURE 4. Diagram showing mineralogic history of the ore deposits. Based on study of hand specimens and thin sections.

range corresponds to that of ferroan dolomite containing 10-30 percent $CaFe(CO_3)_2$. Where the replacing carbonates are fine grained the original serpentine texture is fairly well preserved, but where the carbonates are coarsely granular, the original texture is obscured and the rock resembles a crystalline marble.

Replacement of serpentine by silica has not been so widespread as replacement by carbonates, although the two processes appear to have proceeded simultaneously. The relatively fine-grained type of silica-carbonate rock mapped as "opaline silica-carbonate rock" is characterized by silica mostly in the form of opal mixed with very fine-grained chalcedony and quartz in irregular lens-like or streaky masses which both cut and are cut by the dolomitic carbonate. In the coarsely granular silica-carbonate rock, the silica is almost wholly in the form of clear, glassy, medium-grained quartz.

In slightly altered serpentine, relic chromite and magnetite are present. The former occurs in small specks and the latter usually as dusty "clouds" which form the vague outlines of the original pyroxene or olivine grains. Magnetite also occurs in large octahedrons and is always associated with the carbonates. Invariably the crystals are fractured and filled with veins of carbonate, quartz, and locally, cinnabar. At some localities the magnetite is rather thoroughly limonitized.

Following replacement by carbonates and silica, extensive fracturing occurred. Numerous fractures in the rocks were filled with veins of late carbonate and still later quartz. Locally, cinnabar was deposited during the latter part of the process of vein filling by quartz and shortly thereafter in small, closely spaced fractures, and in interstices between quartz grains throughout the body of the rock. It is fine grained, commonly occurring in grains about a tenth of a millimeter in diameter, and on casual inspection appears to be distributed homogeneously throughout the silica-carbonate rock. In many instances it is difficult to estimate grade or even to identify cinnabar in low-grade ore specimens. Crystalline aggregates of pyrite occur in small amounts throughout the silica-carbonate rock, but most commonly in the coarsely granular type. Limonitization of the pyrite has occurred locally.

The latest fracture filling was by hydrocarbons. This amorphous material, called "bitumen" by the miners, is brownish-black to black in color and is pitchy in luster and consistency. It is found in sporadic masses throughout the mines but is most abundant in the upper levels and is associated with rich concentrations of cinnabar. The writers believe that this well-recognized association is explained by the fact that deposition of both minerals was favored by extensive fracturing of the rock and other structural relations.

Structural Relations

The location of the Mount Jackson-Great Eastern ore deposit was probably determined by several fault systems.

The primary control was exerted by that dominant fault zone of northwesterly strike which was described above as group 3. The localization of the ore deposit along the northern margin of this zone may be due in part to the intersection of the zone with the older, east-trending, nearly vertical fault zone, occupied by the Great Eastern ledge, and described as group 1.

The limitation of the ore deposit to a particular part of the dominant fault zone was probably caused by the local presence of northwest-trending and northeast-trending faults of groups 4 and 5, which were later than group 3 but earlier than the mineralization. The most important of these faults is the northwest-trending fault I, and second in importance is the similar fault III; both belong to group 4. These faults provided conduits for the easy upward passage of quicksilver-bearing hydrothermal solutions through the two serpentine bodies, and also prevented the solutions from migrating westward along the strike of the major fault zone. The sharply defined margin of the ore deposit at the west, where the deposit is bounded by fault I, is in marked contrast to the irregular eastern margin, which was apparently determined for the most part only by a gradual decrease eastward in the intensity of both hydrothermal alteration and cinnabar deposition. The longitudinal projection of the ore deposit (pl. 51) illustrates this contrast.

The later pre-alteration faults trending northeast (group 5) were permeable at the time of alteration and mineralization. Individually these are probably not as persistent as several of the northwest-trending faults (group 4), but they undoubtedly acted as local channelways for solutions, and they seem to have been the feeders for the small, erratic ore shoots in the altered fault breccia.

The pipe-like ore shoots are mainly confined to the west end of the deposit. In general they pitch down the trough formed by the intersection of the footwall of the main or southern serpentine body with fault I. The tabular ore shoots occur throughout the deposit, but most of them lie east of the pipe-like shoots.

Structural control of individual ore shoots is illustrated by the longitudinal projection (pl. 51), in which the shoots are grouped according to their relations to the various faults and intersections of faults. Further details of structural control are shown on the various level projections (pls. 46-48), on the stope level projections (pl. 48), and on the vertical sections (pls. 49 and 50). It will be seen that the shoots may lie under, along, or above one controlling fault, between two controlling faults, or at the intersection of several faults. Almost without exception they are in silica-carbonate rock. The fault or faults controlling an ore shoot are

almost always barren where fault breccia or unaltered serpentine forms both walls. In any such fault, ore is most likely to be found where at least one wall consists of silica-carbonate rock.

The septum of relatively impervious fault breccia separating the two serpentine bodies aided in the control of the various ore shoots by deflecting the ascending solutions. Nearly all the Mount Jackson ore shoots, and several of the Great Eastern ore shoots exploited by the early operators, lie underneath this septum, which is the only known control of the east-trending tabular shoot in the lower levels of the Mount Jackson mine. The western part of the east-trending tabular shoot in the upper levels of the Great Eastern mine is controlled by a similar septum, which does not extend eastward beyond the west end of No. 2 glory hole. East of this point the hanging wall of the shoot is opaline silica-carbonate rock, in irregular gradational contact with the coarsely granular silica-carbonate rock which contains the ore. There is some evidence that the western part of this shoot, backed by the fault breccia, was considerably richer than the eastern part.

Cinnabar coating the walls of fractures in altered fault breccia at some little distance from any silica-carbonate rock occurs at several widely separated places in the Mount Jackson mine. Good ore has been mined in small amount at several of these places but appears to have formed only one definite shoot. This shoot, which is small and pipe-like, is enclosed in the septum of fault breccia between the two serpentine bodies and lies near the west end of the mine. It is exposed on the —150-foot level and again on the —220-foot level. It is apparently at the intersection of the northwest-trending fault I with the later northeast-trending fault B, but fault planes cannot be traced in the altered fault breccia, where their location can only be inferred by projection from exposures in which they bring different rocks together. The fault breccia which consists mainly of sandstone and shale, is here largely replaced by an aggregate of carbonate and silica, and it contains many masses of silica-carbonate rock derived from serpentine fragments that apparently were dragged into the fault breccia by movement along fault I.

Nearly all the silica-carbonate rock within about 30 feet of the stopes in the western end of the Mount Jackson mine is a possible source of low-grade ore. Cinnabar is sparsely distributed through this rock along numerous minute irregular fractures, possibly produced by shrinkage attending the conversion of serpentine to silica-carbonate rock.[5] These fractures allowed the passage of ore solutions in small amount through large masses of rock adjacent to through-going conduits.

The shape and extent of ore shoots deposited by ascending solutions are determined not only by the attitude and extent of the fissures through which the solutions travel, but also by the course of the solutions through those fissures. Solutions may flow upward along a favorable segment of a particular fissure to its intersection with a favorable segment of a higher fissure of different attitude, in which they will continue to rise. At least one example of such a transfer of flow from one fissure to another is represented in the Great Eastern-Mount Jackson ore deposit. The tabular ore shoot that was stoped near the Mount Jackson-Great Eastern end line from the —500-foot level to a point 25 feet above the —415-foot level is controlled by a fault trending northeast. This fault intersects

[5] Knopf, Adolph, An alteration of Coast Range serpentine: Univ. California, Dept. Geol. Sci. Bull., vol. 4, no. 18, p. 428, 1906.

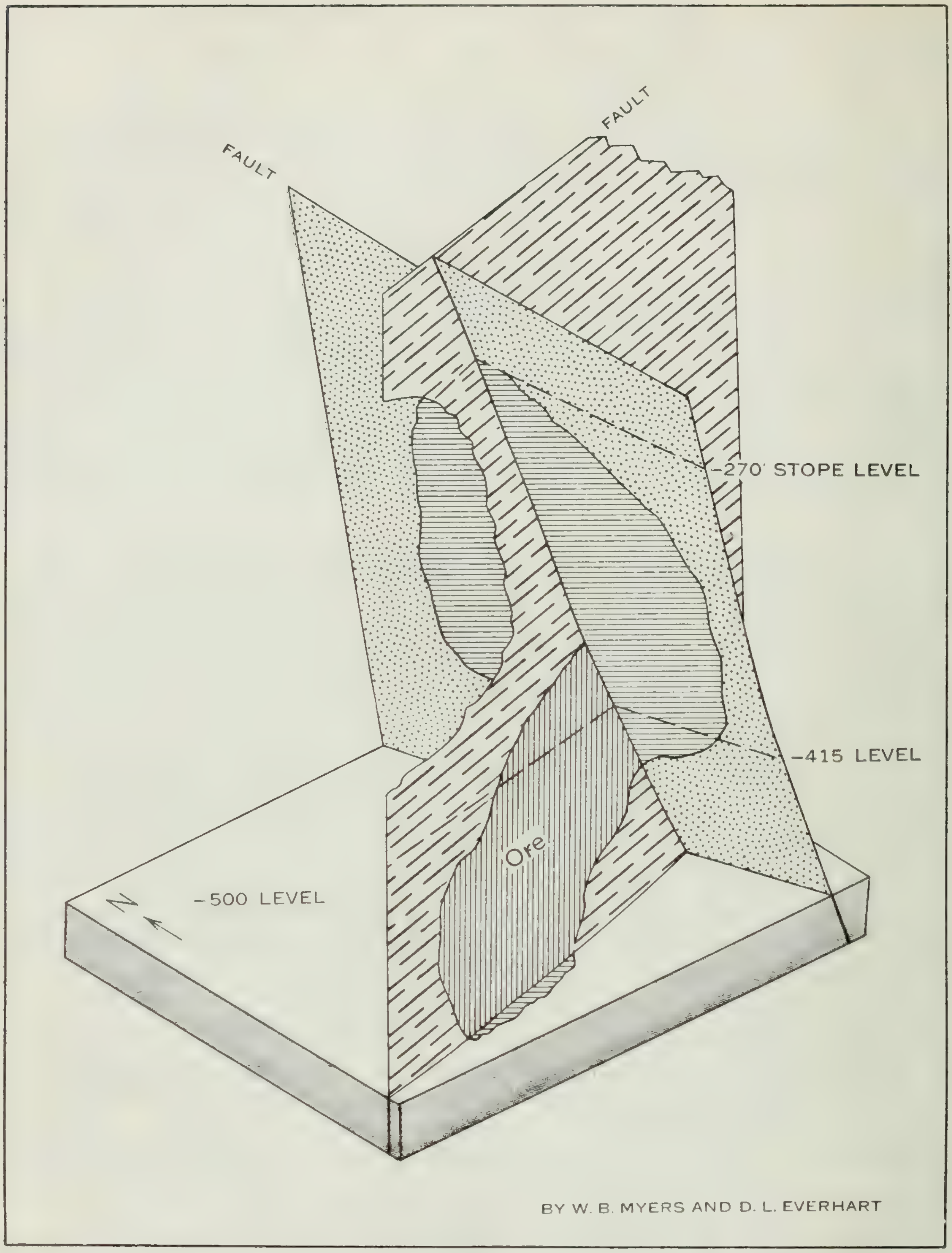

FIGURE 5. Sketch showing compound tabular ore shoot in the lower part of the Mount Jackson and Great Eastern mines.

and slightly offsets a fault trending northwest, which controls the larger tabular ore shoot stoped continuously from the —415-foot to the —270-foot level (see fig. 5).

Size and Grade

The tabular shoot in the upper levels of the Great Eastern mine is developed by a stope 10 feet in maximum width, 300 feet long, 360 feet high, and having a pitch length of 550 feet. The upper part of this shoot was not extensively mined during the early operations, for it was of low grade; most of the ore mined from it near the surface by the present operators yielded from 2 to 2.5 pounds of quicksilver to the ton.

The irregular central pipe-like ore shoot of the Mount Jackson mine is developed by stopes that range from 25 to 135 feet in horizontal dimensions. It has been stoped continuously through a vertical range of at least 670 feet. The yield of the mined-out part of the shoot is unknown, but the ore is believed to have averaged somewhat better than 10 pounds to the ton, which was the average yield of all rock stoped from the deposit in the first period of mining (1875-1906). The figure of 10 pounds of quicksilver to the ton was determined by comparing the recorded production of the first period of mining (1875-1906) with the volume of the stopes mined during that period. This volume was determined largely by mapping done by the writers.

MINES AND PROSPECTS

Mount Jackson Mine

In December 1942 the Mount Jackson mine had five accessible main levels, 67, 150, 220, 360, and 500 feet below the Great Eastern adit level. The mine was flooded below the —500-foot level but was being dewatered, and it was expected that the —620-foot level, the deepest in the mine, would be accessible within a few months. In addition to the main levels there is a large sub-level at —415 feet. The accessible horizontal workings above water totaled about 6,720 feet in length, and there were 540 feet of inaccessible workings.

By examining the projected profile of the stopes and workings of the mines (pl. 51), together with the level maps (pls. 46-48), it can be seen that the mine as a whole has a pipe-like form. Extensive stoping has been done in all the intervals between levels and from the adit level to the surface. Because the silica-carbonate rock and the altered fault breccia are strong enough to stand without timbering in the steeply plunging open stopes, early operators were able to leave an exceptionally small percentage of the ground to serve as pillars.

The Mount Jackson winze, sunk from the —67-foot level in altered fault breccia a short distance northwest of the ore bodies, is ideally located for handling ore from all the existing levels. The ore is hoisted through the winze to the adit level by a Boxco single-drum 4-ton hoist, which has a hoisting speed of 300 feet per minute and a maximum working depth of 1,500 feet. From the collar of the winze the ore is trammed about 350 feet to the ore bin, located a few feet from the Sonoma portal. It is then broken by a sledge until it will pass through a 9-inch grizzly, from which it goes to a Kue-Ken jaw crusher, which has a capacity of 15 tons per hour and reduces the ore to a maximum size of 1½ inches. The crushed ore drops into another bin, from which it is fed by a conveyor belt into two rotary Gould furnaces. The larger

furnace measures 4 by 64 feet and has a capacity of 100 tons; the smaller measures 3 by 48 feet and has a 40-ton capacity. The condensing system is a series of banks of cast-iron pipes 16 inches in diameter and 20 feet high, which exhaust through a redwood stack.

The mine employed 65 men during the summer and fall of 1942.

From September 1940 to December 1942 Sonoma Quicksilver, Inc., burned 64,000 tons of newly mined ore, averaging 4.3 pounds of quicksilver to the ton, and from that time to the end of 1944 they burned 78,176 tons, averaging 5.75 pounds to the ton. This does not include several thousand tons of rock from old dumps burned during the first few months of operation. The total production of quicksilver in this period of a little more than 4 years was 10,242 flasks. Above the —67-foot or adit level, nearly 42,000 tons was mined from a glory hole in the main body of serpentine, and 19,000 tons has been mined in the Wilmot stope, extending from the surface to the —220-foot level. Nearly all the remainder was mined from stopes in the northern serpentine body.

In the following table the ore taken out above the —500-foot level and west of fault III in the Mount Jackson mine prior to December 1942 is classified according to source:[6]

Vertical interval	Main body of serpentine (tons)	Northern body of serpentine (tons)	Total tonnage
From surface to — 67	42,000	16,000	58,000
—67 —220	43,000	11,000	54,000
—220 —360	42,000	0	42,000
—360 —500	28,000	0	28,000
Totals	155,000	27,000	182,000
Grand total			364,000

During 1943, mining was carried down to the —620-foot level, and 29,285 tons was taken from the mine exclusive of the Wilmot stope. By the end of 1944, considerable development had been carried on down to and on the —690-foot level, and 23,016 tons was mined from the underground workings between the —220-foot level and the —690-foot level during that year.

Great Eastern Mine

In 1942, operations in the Great Eastern mine were carried on by Magee Mercury, Inc., from three main levels—the zero or adit level, the —70-foot level, and the —220-foot level. Workings on the —140-foot, —360-foot, and —500-foot levels, which were developed during the earliest period of mining, were open in part but were tightly caved at or near the Great Eastern shaft. During December 1942 a new drift extending northeastward from the Great Eastern shaft was begun on the —500-foot level.

In addition to the main levels there are four sub-levels, one 120 feet above the adit level and the others 310 feet, 335 feet, and 415 feet below that level. The +120-foot level was at one time much more extensive than it was in 1942, having been largely destroyed as a result of the stoping done by the present operators. Above the water level there are about 5,820 feet of accessible horizontal workings and 970 feet of inaccessible workings.

[6] Computed from measurement of areas of stopes on the various level maps and horizontal sections. A ton of silica-carbonate rock is assumed to have a volume of 12 cubic feet.

In the upper part of the mine, as far down as the —140-foot level the workings closely follow the tabular shape of the main serpentine body; they consist of long drifts trending eastward, and short crosscuts to the north and south. The stopes are tabular and also trend nearly due east. Below the —220-foot level, the simple tabular pattern of the upper part of the mine gives way to the complex pattern found in the Mount Jackson mine, of which the lower Great Eastern workings are the eastern extension.

The ore of the Great Eastern mine is brought to the surface from the —220-foot and —70-foot levels through the Great Eastern shaft. From the collar of the shaft and from the portal of the zero level, it is trammed about 360 feet to the ore bin, where it is fed through a grizzly into a 10- by 20-inch Allis-Chalmers Blake-type crusher having a capacity of 5 tons per hour. The reduction equipment consists of an 80-ton Gould rotary furnace, 4 feet by 70, coupled with a condensing system like that of the Mount Jackson plant.

The mine employed an average of 40 men during 1942.

Production started on July 15, 1941. To December 1, 1942, the company produced 1,054 flasks of quicksilver from 34,069 tons of marginal ore with an average yield of 2.35 pounds of quicksilver to the ton, and before closing down, early in 1943, it produced 218 additional flasks (see fig. 3). This production all came from above the —220-foot level, most of it from pillars and from walls of stopes in the large tabular ore shoot between the —140-foot level and the surface. Some pillars still remain in these stopes, but they cannot safely be removed, for the ground in this area does not stand as well as that in the Mount Jackson mine.

Prospects

There are a number of prospects along the strike of the several bands of opaline silica-carbonate rock that trend across the mapped area, but cinnabar was recognized at only one of them. The writers were shown some opaline silica-carbonate rock containing cinnabar that was said to have been taken from the prospect half a mile north of Mount Jackson lookout, but no alteration of the serpentine was noted at this prospect, the only silica-carbonate rock in the immediate vicinity being in several boulders of float.

The prospect showing cinnabar is known as the Roaring Lion, and is located on the Mount Jackson claim, about 500 feet west of a westward-facing scarp of silica-carbonate rock that extends along fault I (see pl. 46). The principal opening is a crosscut adit trending nearly north, which, although tightly blocked with shale 270 feet from the portal, exposes a northwest-trending fault zone similar to that produced by fault I. Two fault-bounded wedges of silica-carbonate rock, enclosed in altered fault breccia, can be seen to extend along the fault zone for a distance of 120 feet. The southern and smaller wedge consists of coarsely granular silica-carbonate rock and shows good colors of cinnabar coating fracture surfaces. Between these two wedges the crosscut intersects a sheet of similar silica-carbonate rock striking N. 65° W. and dipping 35°-60° NE., which contains thin fracture fillings of cinnabar. The northern wedge is less intensively altered than the sheet, though it is thoroughly crushed and sheared. No cinnabar was seen in this wedge. All the silica-carbonate rock exposed in the workings is more than usually fractured, but most of

the movement on the faults by which the wedges and the sheet are bounded occurred before the alteration that produced the silica-carbonate rock.

The southern wedge reaches the surface 20 to 40 feet above the adit, in an outcrop only about 40 feet long and 20 feet wide, trending about N. 40° W. It is enclosed in an elongate outcrop of altered fault breccia. The breccia weathers orange and contains considerable carbonate but no visible cinnabar. The silica-carbonate rock, however, shows colors throughout, and a small cut about 20 feet long across the silica-carbonate rock exposes ore assaying 10 pounds of quicksilver to the ton.[7] There is probably between 25 and 75 flasks of quicksilver in the Roaring Lion prospect between the adit level and the surface.

RESERVES AND OUTLOOK

The outlook for the Guerneville quicksilver district is good, although further production can be expected only from the Mount Jackson-Great Eastern ore deposit and the prospects immediately adjoining it. A considerable amount of measured [8] and indicated [8] low-grade ore remains in the Mount Jackson mine. The chances of finding ore in the virgin ground below the old workings of this mine seem particularly good, but such ore must be classed as inferred.[8] In the Great Eastern mine there is a fair chance of finding ore shoots in the block of virgin silica-carbonate rock which is believed to lie adjacent to the lower workings.

Mount Jackson Mine

The reserves of the Mount Jackson mine as estimated by the writers upon completion of their field work had in great part been mined by the end of 1944, but estimates of reserves as of December 1, 1944, have been submitted by the company and may be summarized as follows:

The mine should yield 1,310 flasks from 15,400 tons of broken ore with an average content of 6.5 pounds of quicksilver per ton, and 4,730 flasks from 45,500 tons of unbroken ore with an average content of 7.9 pounds of quicksilver per ton, making a total of 6,040 flasks of reasonably assured quicksilver. In addition, 1,830 flasks may be produced from 20,700 tons of possible ore with an average content of 6.7 pounds of quicksilver per ton.

It seems reasonable to assume that the ore in the virgin ground in the bottom parts of the mine is of considerably higher grade than the marginal rock left by the early operators above the —620-foot level. There is every reason for optimism regarding continued mining at depth, and the sizeable quantities of assured reserves in the mine should, under economic and manpower conditions obtaining in 1945, maintain its production level of around 3,000 flasks per year.

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[7] Wickam, Stanley F., superintendent of the Mount Jackson mine, oral communication.

[8] *Measured ore* is ore for which tonnage has been computed from dimensions revealed in outcrops, workings, and drill holes, and for which the grade is computed from the results of detailed sampling. *Indicated ore* is ore for which tonnage and grade are computed partly from specific measurements, samples, or production data, and partly from projection for a reasonable distance on geologic evidence. *Inferred ore* is ore for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements.

Roaring Lion Prospect

As previously stated, the silica-carbonate rock at the Roaring Lion prospect above the adit may contain enough ore to produce between 25 and 75 flasks of quicksilver. As a present source of production this prospect is not important, but if the coarsely granular silica-carbonate rock persists far below the adit level it may contain valuable ore shoots, and the fault zone should be prospected at depth.

Great Eastern Mine

The measured and indicated reserves of the Great Eastern mine are small, but the inferred reserves may be considerable. The recoverable ore above the —500-foot level would probably not yield more than 500 flasks of quicksilver. Much of this, moreover, would have to come from rock that carried only 2 to 2.5 pounds to the ton, which the present operators regard as marginal ore. The records of Magee Mercury, Inc., show that during the period December 1941 to December 1942, the company sustained a loss of more than $11,000 on 614 flasks produced from rock that averaged 2.05 pounds of quicksilver to the ton (see fig. 3). To have avoided a loss, the rock burned would have had to average at least 2.3 pounds to the ton.

New ore in the Great Eastern mine is most likely to be found in a body of silica-carbonate which is thought to be present at depth in the hanging-wall block of the northwest-trending fault III, a short distance southeast of the present lower workings. Further prospecting on the eastern extension of the Great Eastern outcrop might discover small, shallow ore shoots, but the area is so far from the center of intense alteration and mineralization that it seems unlikely to contain any large and persistent shoots.

MINING LAW IN RECENT YEARS†

By William E. Colby *

It is now over thirty years since the third and last edition of *Lindley on Mines* was published. In this interim many important decisions involving mining law have been handed down, and equally important legislation has been enacted by Congress. The Supreme Court of the United States, the court of last resort on this particular subject, has during these years spoken many times in deciding critical cases involving various aspects of the law.[1] Judge Curtis H. Lindley,[2] the author of *Lindley on Mines,* was a lawyer of exceptional ability and during his lifetime was recognized as the leading authority on mining law in America. In the preparation and editing of his outstanding work on the law of mines he demonstrated that he was equally able as an author. Judge Lindley became interested in mining law in its formative period. Prior to the appearance of the first edition of *Lindley on Mines* in 1897 the few published books dealing with mining law were little more than copies of the statutes and digests of the decided cases.[3] The law had not developed sufficiently to warrant a systematic and philosophical treatment of the subject. It is fortunate for the profession that a man of such outstanding ability undertook this work when he did. Mining law was rapidly developing and its principles crystallizing. Many of our law textbooks are written by men who have had little experience in active practice. Few busy lawyers can or will give the time and labor involved in writing texts. Judge Lindley was the rare exception. The demand for a second edition was met in 1903; and in 1914 the third appeared. The latter was truly a *magnum opus,* and takes rank with the best law treatises that we have. Judge Lindley reached the greatest height in his professional work at the very time that mining law was at its zenith. Since then, mining litigation has decreased in importance and number of cases.[4]

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† Reprinted from *California Law Review*, vol. 33, September 1945, no. 3, pp. 368-387.

This series of articles, of which the following is the first, is intended to supplement the 3rd edition of "Lindley on Mines" (1914), and bring the mining law as it has since developed, down to date. It is obviously impossible in the allotted space to present the subject in detail in all of its aspects. To treat it exhaustively would require a large volume. Only the more important legislation and decisions will be considered and, because the Supreme Court of the United States is the final arbiter in all cases involving federal public lands, the decisions of that court will receive special consideration. Land laws related to the mining laws will also receive some consideration, as was done in Lindley on Mines. The order in which the sub-titles to be discussed are here presented will, in the main, follow the same order in which they appear in Lindley on Mines.

* Member of the San Francisco Bar; Lecturer on the Law of Mines and Waters, University of California, 1911-1937; LL.D., University of California, 1937; assistant editor, 3rd ed. Lindley on Mines (1914).

1 While some commendable books on mining law have appeared in the meantime, none of them purports to give more than a bare outline of what the cases have decided and there is very little attempt at analysis of, or comment on, underlying principles. The 16th edition of Morrison's Mining Rights was published in 1936 and a revised 4th edition of American Mining Law by Ricketts was published in 1943 by the Division of Mines of the State of California. This latter volume is especially creditable and furnishes a ready reference for decided cases, bringing them up to the date of its publication.

2 Judge Lindley gave a course of lectures on mining law at the University of California and received the degree of LL.D. from that institution in 1917. See *Curtis Holbrook Lindley* (1850-1920) an account of his life and accomplishments by the writer in (1921) 9 Calif. L. Rev. 87-99.

3 Mining Claims and Water Rights (1869) by Yale was the leading pioneer work. Copp's U. S. Mineral Lands appeared in several editions as did also Morrison's Mining Rights and Weeks on Mineral Lands. Sickels' Mining Laws and Decisions was published in 1881.

4 All one has to do is to note the number of mining cases appearing in the reports to realize that mining law is on the wane. This is only to be expected, for no new mining fields of outstanding importance have been discovered in recent years, the older camps have in many instances been entirely worked out, and the large corporations which have taken over the more important mining operations have profited by past experience and, with foresight, forestalled prospective litigation by avoiding in advance possible sources of legal trouble.

This has one great disadvantage to a mining lawyer nowadays, for, while in Judge Lindley's day there were many judges familiar with the problems of this specialty, they having previously been active in the field of mining law,[5] it is rare today for a judge to try a mining case who has had any previous familiarity with the subject.[6]

Introduction. To understand mining law as it exists today in the United States, one must know something of the historical background which is responsible for the different types of mining law in force in various parts of the United States. The thirteen original colonies achieved their independence as sovereign powers and, consequently, when they formed a confederation and later on, the Union, they each had complete sovereign powers over the public lands within their respective borders, and legislated regarding such lands, including mineral lands, as each saw fit. (The same is true of Texas.) When these states ceded to the United States the public lands lying west, and between them and the Mississippi River, the United States could have adopted a uniform code of mining laws applicable to these lands. However, comparatively few mineral deposits were known and mined in this territory and, with the exception of legislation providing for the leasing of deposits of lead in a limited area,[7] Congress did not act. It later abandoned this lead-mine leasing policy as impractical, and disposed of these and other mineral lands on the same basis as agricultural lands.[8]

With the acquisition of the vast areas of public domain embraced in the Louisiana purchase in 1803, the Florida cession in 1821, California and adjacent territory conquered from Mexico (treaty of 1848), the area in the southwest included in the Gadsden purchase of 1853, and the area in the northwest confirmed by the treaty with Great Britain, the United States came into possession of a veritable empire containing a hidden and then unknown mineral wealth unrivaled the world around.

The discovery of gold in California in 1848 started a new trend in thought on the subject. In the stirring days of '49, men from all parts of the world, but principally from the eastern states, rushed to this new El Dorado to make their fortunes mining gold. Gold was found with few exceptions on public domain owned by the United States. Congress had not legislated, so that it was impossible to legally acquire title to these lands. The Mexican mining laws were held to be inoperative. The miners were technically trespassers, and the gold they mined belonged to the United States. To avoid bloodshed and unseemly contests over possession and working the gold-bearing lands, the miners took

[5] We had Justices Field, Brewer, McKenna, Sutherland and Van Devanter, of the United States Supreme Court, Chief Justice Beatty and Justices Temple and McFarland, of the State Supreme Court, and Judges Morrow, Gilbert and Ross, of the Ninth United States Circuit Court of Appeals, to mention some of the leading jurists who were familiar with mining law, besides many trial judges, who knew without any telling its underlying principles.

[6] The writer must confess, however, that many of these comparatively inexperienced judges in mining cases have exhibited great ability in grasping technical mining problems once they have been presented and explained. Still, it is not the "easy sailing" that it used to be when little time had to be expended in explaining basic principles of mining law to the courts, because already thoroughly understood by them.

[7] 2 Stats. at Large, 488. It is interesting to note that Congress provided for the leasing of lead mines, instead of the outright sale of the lands containing them, in its first mining legislation. This was because of the great importance of lead as ammunition for use in war. This policy of leasing mineral lands was later abandoned by Congress and only revived as to strategic minerals, oil, gas, coal, phosphate, potash, etc., in recent years. The Continental Congress had in 1785 enacted a law reserving one-third part of all gold, silver, lead and copper mines in the "western territory" but after the Constitution was adopted, the new Congress did not reenact it.

[8] See Lindley on Mines, §§33-35. Wherever Lindley on Mines is cited in this series of articles the references are to the 3rd edition.

matters into their own hands, formed mining districts, held district meetings and adopted their own rules and regulations, which became the "customs of the diggings," and which specified the amount of ground that each miner was entitled to work and the manner of working, etc.[9] This general policy, fixed and regulated by these rules and customs, was approved by the silent acquiescence of the federal government, and was expressly sanctioned by the Supreme Court of the United States.[10] It received formal confirmation at the hands of Congress by the Act of 1866. This extraordinary situation, of the United States, by sufferance, and in the absence of Congressional legislation, permitting the miners to have their own way and possess and work the mining ground in accordance with rules of their own making, which rules were for all practical purposes "the law of the land," recognized as such by the courts, is without parallel in the history of the world.[11] The enormous federal debt, over a billion dollars, resulting from the civil war,[12] caused officials, who were solicitous for the credit of the country, to suggest that these mining lands in the West should either be leased on a royalty basis or sold to the highest bidder so that the nation might derive some revenue from its own property from which millions upon millions of dollars in gold value were being taken annually without a cent being contributed to it, the lawful owner.

Act of 1866.[13] The pressure on Congress to do something became so strong that the western members realized that it was up to them to take some positive action to meet the situation and in some measure protect their mining constituents. Led by Senators Stewart of Nevada and Conness of California, a bill was hastily drafted, patterned in large part on the rules and regulations the miners had adopted in their mass-meetings. The Act of 1866 (*14 Stats. at Large, 251*) resulted and, though the first draft provided for the payment of royalty on all ore extracted, this provision was eliminated from the Act as passed. It gave legal sanction to the presence of the miners and the staking out and mining of locations on public domain, and exacted no payment of any sort for the grant of this privilege for, and the confirmation of, what had previously taken place under sufferance. Only when patent for the land was applied for was any payment required, and the price even then was nominal.

An interesting case[14] arose in this county (Alameda), involving the Central Pacific Railroad right of way granted by Acts of Congress in 1862 and 1864.[15] This right of way conflicted with a public highway in Niles Canyon, maintained ever since 1859. The Supreme Court of the United States held that the right of the county to the public highway

[9] A complete description of this exciting period will be found in LINDLEY, *op. cit. supra* note 8, §§40-49. Also see Colby, *The Extralateral Right: Shall It Be Abolished?* (1916) 4 CALIF. L. REV., 437-452.

[10] California-Oregon Power Co. v. Beaver Portland Cement Co. (1935) 295 U. S. 142, 154. In another case the Supreme Court intimated that, by the government's silent acquiescence and the implied congressional consent, the miners acquired "a privilege in public land." United States v. Midwest Oil Co. (1915) 236 U. S. 459, 475.

[11] RICKARD, MINES AND METALS (1932) c. 13.

[12] Who at that time would have believed that, only seventy years later, this country would be spending billions of dollars each month without fatal strain on its treasury?

[13] LINDLEY ON MINES, §§53-61. As a matter of fact, Congress had much earlier incidentally recognized in several of its Acts the fact that miners were occupying and mining on the public domain. These acts are noted at the foot of page 571, U. S. v. Sweet, 245 U. S. 563. And see also the following: 10 STAT. (1851) 926, 932; 10 STAT. (1853) 244, 246; 13 STAT. (1863) 673, 674; 13 STAT. (1863) 681, 682; 13 STAT. (1865) 567; 13 STAT. (1865) 440-41; 13 STAT. (1865) 469, 473; 14 STAT. (1866) 43; 14 STAT. (1866) 242-43. 245 U. S. 563.

[14] Central Pacific Railway v. Alameda County (1932) 284 U. S. 463.

[15] 12 Stats. at Large 489 and 13 *ibid.* 356.

was confirmed by the provisions of the Mining Act of 1866 (*14 Stats. 251*, §8), which act even though subsequent to the railroad granting acts, not only granted rights upon the public domain subsequently initiated, but also recognized, and confirmed, *preexisting* rights. This interpretation of the act in its bearing on rights to mineral lands of the public domain which had attached prior to the act, is of sufficient importance to justify the following quotation from the court's opinion:

"By the Act of July 26, 1866, c. 262, 14 Stat. 251-253, Congress dealt with the acquisition of a variety of rights upon the public domain. By §§1-7, mineral lands, whether surveyed or unsurveyed, are open to exploration and occupation, subject to regulations prescribed by law, and to the local customs and rules of miners in the several districts." (468)

The court cites the case of *Broder v. Water Co.*, 101 U.S. 274, involving a right of way to a canal constructed across the public domain in 1853, which right of way it upheld as against a tract of subsequently patented railroad land issued under the railroad land grants of 1862 and 1864, and quotes from that case to the effect that the section of the Act of 1866 granting these rights of way—

"was rather a voluntary *recognition of a pre-existing right of possession*,[16] constituting a valid claim to its continued use, than the establishment of a new one." (469-470)

The opinion in the *Central Pacific Railway* case goes on to say:

"Likewise, this court has recognized that the appropriation of mineral lands upon the public domain in accordance with the local customs of miners, prior to Congressional legislation, was assented to by the silent acquiescence of the government, and was entitled to protection. . . ." (Citing cases, 471)

and also quotes from *Jennison v. Kirk*, 98 U. S. 453, that the Act of 1866:

". . . merely recognized the obligation of the government to respect private rights which had grown up under its tacit consent and approval. It proposed no new system, but sanctioned, regulated, and confirmed a system already established, to which the people were attached." (98 U. S. 459)

The *Central Pacific Railway* case concludes that these rights granted by the Act of 1866

". . . were such rights as the government in good conscience was bound to protect against impairment from subsequent grants. . . ." (473)

It was not long after this decision before another case arose in California [17] involving mining claims located in the early 1860's. There, extralateral mining rights conflicted with land patented under a railroad grant. (*14 Stats. at L. 239*, enacted July 25, 1866.) The point was made by the parties claiming under the railroad grant that the Mining Act of 1866 was passed on July 26, or one day later than the railroad grant act and that, therefore, the latter act, being prior in time, took precedence over the mining act grant. The Supreme Court of California, however, followed the United States court rulings just noted and held:

"It is clear that Congress intended by the Mining Act of July 26, 1866, to recognize and give legal validity to all existing mining claims in accordance with local rules and regulations, including extralateral rights in those lands to which such rules and regulations applied. . . . (218) [T]he Railroad Grant Act of July 25, 1866, upon which plaintiffs rely for their original title, specifically excepted from its operation all mineral lands. The terms of the act make it clear that Congress did not intend to vest in the railroad title to any mineral lands of the United States. . . ." (219)

This case will be discussed at greater length hereinafter under subtitles "Railroad Grants" and "Extralateral Rights."

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[16] Underscoring is the court's.

[17] Ames v. Empire Star Mines Co., Ltd. (1941) 17 Cal. (2d) 213, 110 Pac. (2d) 13; *cert. den.* (1941) 314 U.S. 651.

The Act of 1870.[18] The Act of 1866 had confirmed the rights of miners to lode, or ledge, or vein, claims, and had said nothing about placer or gravel claims, though it was generally conceded that the introductory provision of the Act of 1866 throwing the "mineral lands of the public domain . . . open to exploration and occupation" was broad enough to include placers. The so-called Placer Act of 1870 (*16 Stats. at Large, 217*) expressly provided for the location of placer mining claims, without requiring any payment to be made to the government, excepting a very nominal price per acre in the event the locator desired to obtain a patent, and whether he applied for one or not was, as in the case of lode locations, left to his option.

The Act of 1872.[19] The experience gained from the practical operation of the Acts of 1866 and 1872 brought about a demand for certain changes. Senator Stewart of Nevada, who was still in the Senate, again sponsored the legislation which was enacted and is generally referred to as the Act of 1872. (*17 Stats. at Large, 91,* but later codified with other related legislation as §§ *2318-2346 U. S. Rev. Stat.*) This Act deals with the location and patenting of both lode and placer mining claims and is today, and has been for nearly three-quarters of a century, the basic law governing the acquisition and maintenance of title to mining claims on the public domain. It has been amended from time to time in certain minor respects; and lands containing certain non-metallic minerals have been removed from its operation. These changes will be noted hereinafter, but, as far as metalliferous lands are concerned, this act continues unchanged the principle of free mining on the public domain. Because it is the basic mining law, decisions of the courts interpreting it are numerous and the late cases will be considered hereinafter under appropriate headings.

Leasing Act of 1920 and Related Acts. These mining statutes, reviving the early policy of leasing of lead mines, were enacted subsequent to the publication of the last edition of *Lindley on Mines,* and hence could not be noted there. However, Judge Lindley was deeply interested in the conservation movement which resulted in the withdrawal by the President (without express sanction of Congress) from entry of public lands containing certain strategic minerals essential to the safety and well-being of the inhabitants of the country at large, and, noting what Congress and the chief officials of the government were doing in anticipation of this complete reversal in mineral land policy from the previous policy of free mining and granting unrestricted title, he made some illuminating comments on this subject.[20] It has also been elsewhere treated by the writer of this article.[21]

Judge Lindley, as were the great majority of lawyers in the mining states of the west, was very definitely of the opinion that these presidential withdrawals of potential oil land were invalid.[22] President Taft had expressed grave doubt as to his authority to make these extensive withdrawals of lands of the public domain from entry in the absence

[18] LINDLEY ON MINES, §§62-63.
[19] *Ibid.,* §§68-74.
[20] *Ibid.,* §§200 and 200a, b and c.
[21] Colby, *The Law of Oil and Gas* (1942) 30 CALIF. L. REV. 245, 254-271. Colby, *The New Public Land Policy,* etc. (1915) 3 CALIF. L. REV. 269.
[22] LINDLEY, *op. cit. supra* note 18, §200b. See also Colby, *The New Public Policy with Special Reference to Oil Lands* (1915) 3 CALIF. L. REV. 269. In Mason v. United States (1923) 260 U.S. 545, the court said, "It is common knowledge that the validity of the withdrawal order . . . was in grave doubt until the decision of this court in United States v. Midwest Oil Co." (556), 3 CALIF. L. REV. 269-291.

of congressional approval, especially when the mining laws then in force gave express sanction to the location of such lands. Though Congress gave the President this authority to withdraw lands by the Act of June 25, 1910,[23] there were many locations of oil lands made between the original presidential withdrawals of 1908 and 1909, and his confirmatory withdrawal of the same and additional lands immediately following the passage of this Act. The validity of these pre-Act locations was in violent dispute. The year following the appearance of the third edition of *Lindley on Mines* (1914), the Supreme Court of the United States set the matter at rest in *United States v. Midwest Oil Co.* (1915), 236 U. S. 459, though by a divided court, three Justices dissenting.[24] The authority of the President was upheld, based on the long continued practice of the President in making withdrawals of land for various purposes, all of which had been acquiesced in by Congress, either silently or by making appropriations of money for the benefit of lands thus withdrawn.[25]

The Leasing Act of 1920 (*41 Stat., 437*) inaugurated a new policy, and abolished the former practice of location of mining claims which contained the minerals specified in the Act, viz.: coal, oil, oil-shale, gas, phosphate and sodium.[26] Such lands are no longer open to location and acquisition of title, but only to lease.[27] Potash had been originally included in this group, but the urgent need for making potash available for war purposes resulted in Congress passing an act in 1917 providing for the leasing of lands containing potash. (*40 Stats., 297.*) This act was later repealed and superseded by another potash act in 1927 and noted hereinafter.

In 1914 Congress had passed an Act in furtherance of the conservation policy (*38 Stat., 509*), which was part of the contemplated legislation to follow the earlier withdrawal of lands containing oil and other minerals embraced in that policy. This Act provided for the separate disposal of the surface of land to agricultural claimants, and the severance of the underlying specified minerals which were reserved for later disposition. The Act did not become operative for practical purposes, as far as the leasing and removal of minerals is concerned, until the passage of the Leasing Act of 1920, which provided the legal machinery whereby government leases on such patented lands might be obtained. Persons who have qualified by filing a bond for payment of damages to crops and improvements of the agricultural occupant of the surface, may prospect and mine the reserved minerals. The Act of 1920 provides for the disposal of such reserved mineral deposits through leases from the government entitling the lessee to remove them and make the necessary use of the surface and pay royalties, and in some instances

[23] 36 Stats. at L. 847. This Act also gave the President authority to withdraw lands for water power sites and other purposes.

[24] The dissenting justices included McKenna and Van Devanter, who were from the west and were unusually familiar with land law involving the public domain so that they wrote most of the court's opinions in such cases.

[25] See 3 CALIF. L. REV. 269, for a full discussion of this case. This withdrawal power of the President has been reaffirmed in a comparatively recent case where public lands had been withdrawn for occupancy as an Indian reservation. Sioux Tribe v. United States (1942) 316 U.S. 317, 325.

[26] Ickes v. Virginia-Colorado Dev. Corp. (1935) 295 U.S. 639, 646. The Act has been amended many times. See Colby, *The Law of Oil and Gas* (1942) 30 CALIF. L. REV. 245, 263-264. An interesting case involving borates of sodium under the leasing act is Burnham Chemical Co. v. United States Borax Co. (1933) 54 L.D. 183.

[27] Wilbur v. Krushnic (1930) 280 U.S. 306, 314. For a detailed INTERPRETATIONS OF THE MINERAL LEASING ACT and the amendments thereto, see 56 L.D. 174-196.

further compensation, to the United States. A servitude is laid on the surface estate for the benefit of the mineral estate, to the end that the United States may realize a proper return from the extraction and removal of the reserve minerals. The only compensation which the surface owner may rightfully demand is for damages caused by mining operations. Damage to crops and agricultural improvements are intended, and not damage to improvements placed on the land after mining operations are under way, and which are obviously incompatible with those operations. In the leading case on the subject, the surface owner was subdividing the land, and selling town lots. The government's lessee was successful in preventing such development, so foreign to agricultural use of the land.[28]

To effectuate the conservation policy of President Hoover, Secretary of the Interior Wilbur in 1929 issued a general order, and refused to entertain applications made under the Act of 1920 for permits to prospect for oil and gas. He also cancelled all pending applications. This action was taken because of an enormous increase and troublesome surplus of petroleum. The over-supply was glutting the market, and "cutthroat" tactics of producers and dealers were aggravating a serious situation.[29] In a suit to test the Secretary's power to take this drastic step, the Supreme Court of the United States upheld his authority, stating that the general powers of the Secretary over the public lands as guardian of the people, and the right of the President to withdraw public lands from private appropriation, supported the Secretary in his general order.[30]

The Leasing Act expressly excepted from its operation prior "valid claims" to the land sought to be leased. However, this exception was not intended to include "nebulous and insubstantial" claims such as the mere privilege of contesting possible presumptive titles. The Act is not operative where substantial rights had already been acquired to lands containing these leasable minerals. It was enacted in order to permit the exploitation of lands subject to lease by lessee applicants, and was conditioned on the payment of royalties to the government.[31]

An interesting question which arose in the administration of the Leasing Act was whether unpatented mining locations that were "valid claims existent at date of the passage of this Act," and thus excepted from its operation, would remain "valid claims," and continue to be excepted from its provisions, if the owners failed to perform the assessment work, or annual labor, as it is called, required by the mining law [32] to keep the location alive and in good standing. The Land Department had held that certain oil shale locations were null and void because of such failure to perform assessment work. The Supreme Court of the United States reversed this ruling, holding that the mere failure to do the work does not *ipso facto* forfeit the claim, but only renders it subject to loss by relocation. The owner is permitted by the mining statute to resume work and "such resumption does not *restore a lost* estate . . . it *preserves* an *existing* estate." [33] The court intimated that some sort of challenge on

[28] Kinney etc. Oil Co. v. Kieffer (1928) 277 U.S. 488, 490-1, 494-5, 504-5.

[29] This over-production situation and the remedies resorted to by the oil producing states and the federal government in their attempt to curb the evil results of such superabundance are detailed in Colby, *op. cit. supra* note 26, at 245, 266-271.

[30] United States v. Wilbur (1931) 283 U.S. 414, 419.

[31] Work v. Braffet (1928) 276 U.S. 560, 565-566.

[32] U. S. Rev. Stats. §2324.

[33] Wilbur v. Krushnic (1930) 280 U.S. 306, 316-318. The italics are the court's. See Oil Shale Placer opinion by the Land Department (1933) 54 L.D. 244.

behalf of the United States of this failure to perform annual labor might operate to defeat the title.[34] Acting on this suggestion the Land Department tested this intimation and challenged the failure to perform the assessment work in a subsequent case. The court held, however, that a mere challenge by the government of the validity of the location on the ground that assessment work had not been performed was not sufficient, and did not furnish a proper basis for declaring the claims null and void.[35]

Enlarging its leasing policy, Congress, on April 17, 1926,[36] provided for the prospecting under permit and leasing of lands for sulphur in Louisiana; and, on June 8, 1926,[37] for the leasing of lands embraced in any land claim confirmed by the Court of Private Land Claims, where the mineral rights did not pass to the grantee, for gold, silver, or quicksilver deposits, or mines or minerals of the same; and, on February 7, 1927,[38] for prospecting under permit and leasing lands for chlorides, sulphates, carbonates, borates, silicates, or nitrates of potassium.

Public Lands-Public Domain. The expressions ''public land'' and ''public domain'' are equivalent, are used interchangeably, and have acquired a settled meaning in the legislation of this country.[39] The words ''public lands'' are habitually used in federal legislation to describe such lands as are subject to sale or other disposal under general laws,[40] and, conversely, lands which have been appropriated or reserved for a lawful purpose are not public, and are to be regarded as impliedly excepted from subsequent general laws, grants and disposals which do not specially disclose a purpose to include them, and this is the case even though the appropriation and reservation be afterwards set aside.[41] However, the use of these words in Acts of Congress is one of intention. Though they are seldom employed as including lands selected for or allotted to Indians, they sometimes are so used where the United States has retained title. The nature and object of the particular statute must be considered in determining the question.[42] ''Public lands'' do not include lands to which rights have attached and become vested through full compliance with the applicable land law.[43] Therefore, tide lands, which belong to the states, and which, prior to statehood, are held in trust by the federal government for future states, are not ''public lands.''[44]

Under the Constitution (Art IV, §3) Congress has plenary power to dispose of and make all needful rules and regulations respecting pub-

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[34] *Ibid.* at 318.

[35] Ickes v. Virginia-Colorado Dev. Corp. (1935) 295 U.S. 639, 646. See The Shale Oil Co. (1935) 55 L.D. 287.

[36] 44 Stats. at Large 301. See Regulations under the Act, 51 L.D. 647-649. See also amending act of July 16, 1932, 47 Stat. 401.

[37] 44 Stats. at Large 710.

[38] *Ibid.* at 1057. This Act expressly repealed and superseded the POTASH LEASING ACT of Oct. 2, 1917 (40 Stats. at L. 297).

[39] Barker v. Harvey (1901) 181 U.S. 481, 490.

[40] Borax Ltd. v. Los Angeles (1935) 296 U.S. 10, 17.

[41] United States v. Minnesota (1926) 270 U.S. 181, 206; United States v. O'Donnell (1938) 303 U.S. 501, 510.

[42] Kindred v. Union Pacific R. R. Co. (1912) 225 U.S. 582, 596; Nadeau v. Union Pacific R. R. Co. (1920) 253 U.S. 442, 444, 446; Larkin v. Paugh (1928) 276 U.S. 431, 438.

[43] Missouri etc. Ry. Co. v. United States (1914) 235 U.S. 37, 39-40; La Roque v. United States (1915) 239 U.S. 62, 68; United States v. Henner (1916) 241 U.S. 379, 385-6; Payne v. Central Pac. Ry. Co. (1921) 255 U.S. 228, 238; Copper Belt etc. Mining Co. (1934) 54 L.D. 475, 479; also see LINDLEY ON MINES §§112, 322.

[44] Borax Ltd. v. Los Angeles, *supra* note 40. (But see the recent case of United States v. California, 332 U. S. 19 and 67 S. Ct. 1658, upsetting this previously generally accepted doctrine that the states owned the tide lands.)

lic lands of the United States.[45] As we have already noted, the President may, because of a long established exercise of such authority, acquiesced in by Congress, withdraw public lands, even from future private entry under existing laws authorizing such entry, though ''valid rights'' which have already attached will not be affected by such withdrawals.[46] The federally owned public lands are held in trust for all the people; and in providing for their disposal, Congress has sought to advance the interests of the whole country by opening them to entry in comparatively small tracts under restrictions designed to accomplish their settlement, development and utilization.[47]

The general government was charged through Congress with the duty of disposing of the vast empire in the West, not only as owner desiring to realize a return from such sale, but because the settlement and development of the country in which the lands lay was highly desirable. To these ends, Congress passed the mining laws, the preemption and homestead laws, and other laws having for their object the disposal of these lands. It also, by making large land grants to aid in the building of the Pacific and transcontinental railroads, had encouraged and assisted in the settlement and parcelling out of this immense landed estate.[48] The policy under which the United States administers its land laws is not that of an ordinary proprietor seeking to sell real estate at the highest possible price, but it offers it on liberal terms to encourage the citizen and to develop the country. The government does not deal at arm's length with the settler or locator.[49]

The public land is property of the United States, and the land laws are not of a legislative character in the highest sense of the term (Art. 4, §3), ''but savor somewhat of mere rules prescribed by an owner of property for its disposal.'' These rules or laws for disposal are necessarily general in their nature. The power of Congress over the public domain has a dual aspect, for it not only has legislative power, but it also exercises the powers of a proprietor as well. Congress may deal with such lands precisely as a private individual may deal with his own property. It may sell or withhold them from sale. Like any other owner, it may provide when, how, and to whom its land can be sold, and can permit it to be withdrawn from sale. It may sanction some uses and prohibit others, and may forbid interference with such as are sanctioned. Like any other owner, it can waive its strict rights, as it did when it suffered without compensation, the valuable privilege of grazing cattle on such lands, the custom being one of one hundred years standing,[50] and, by its silent

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[45] Sinclair v. United States (1929) 279 U.S. 263, 294. In this case the power of Congress to compel a witness to answer questions at a committee hearing involving public lands was upheld.

[46] See *supra* discussion of power of withdrawal of public lands from entry under the heading LEASING ACT OF 1920, etc.

[47] Causey v. United States, 240 U.S. 399, 402.

[48] California Oregon Power Co. v. Beaver Portland Cement Co. (1935) 295 U.S. 142, 156-157.

[49] El Paso Brick Co. v. McKnight (1914) 233 U.S. 250, 258.

[50] Just as the miners, without statutory sanction, exercised the privileges of mining on public domain from the discovery of gold in 1848 to the Act of 1866, so the stockmen and sheepmen from earliest days had exercised the right of grazing their cattle, horses and sheep on the public domain without paying for the privilege. See Omaechevarria v. Idaho (1918) 246 U.S. 343, 346-352 and notes on the subject. Since that case, Congress passed an act in 1934 regulating grazing on the public domain (48 Stats. at Large 1270).

Since the creation of the National Forests (originally called Forest Reserves or Reservations) grazing within those areas has been regulated by the National Forest Service. See Utah Power and Light Co. v. United States (1917) 243 U.S. 389 for details of this forest legislation.

acquiescence, assented to the general occupation of these lands for mining, private persons thereby acquiring a privilege in public land by virtue of an implied congressional consent.[51]

The states may prescribe police regulations applicable to federally owned public land areas, so long as the regulations are not arbitrary or inconsistent with applicable congressional enactments. The state power extends to quarantine rules and measures to prevent breaches of the peace and unseemly clashes between persons privileged to go upon or use such areas.[52] While the states have such civil and criminal jurisdiction over nationally owned lands within their respective limits, this does not extend to any matter that is inconsistent with the full power of the United States to protect its own lands, to control their use and to prescribe in what manner rights in them may be acquired.[53] In certain instances, for example in the case of National Parks, the states have ceded to the United States some of their jurisdiction, particularly criminal, but have usually retained the power to tax privately owned property. They have also political jurisdiction, so that the residents of the area may still participate in state controlled elections.[54]

Congress also has the power to prohibit acts upon privately owned land, such as the setting of fires, which may imperil publicly owned forested lands.[55]

Mineral Lands. Not all lands owned by the United States are subject to disposal and acquisition under the mining laws for their mineral deposits, but only those where the United States has so indicated. These mining laws never apply where the United States directs that the disposal be only under other laws.[56] Alabama, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Ohio, Oklahoma and Wisconsin are ''public land states,'' but have been wholly or partly excepted from the operation of the mining laws.[57] Arizona, Arkansas, California, Florida, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington and Wyoming are public land states in which the federal mining laws are operative. They also extend to Alaska.

In its legislation concerning the public lands, it has long been the practice of Congress to make a distinction between mineral lands and other lands, to deal with them along different lines, and to withhold mineral lands from disposal, save under laws specially including them.

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[51] Omaechevarria v. Idaho (1918) 246 U.S. 343, 352; United States v. Midwest Oil Co. (1915) 236 U.S. 459, 474-5; McKelvey v. United States (1922) 260 U.S. 353, 359; Sinclair v. United States (1929) 279 U.S. 263, 297.

[52] McKelvey v. United States (1922), *supra* note 51; Omaechevarria v. Idaho, *supra* note 51, at 343, 346-7.

[53] Utah Power & Light Co. v. United States (1917) 243 U.S. 389, 404. "The United States may preform its functions without conforming to the police regulations of a state." Arizona v. California (1931) 283 U.S. 423, 451.

[54] A typical statute whereby the State of California ceded partial jurisdiction over the Yosemite, Sequoia and General Grant National Parks, is Cal. Stats. 1919, c. 52, p. 74.

[55] United States v. Alford (1927) 274 U.S. 264, 267. And the fact that the lands have been reserved from sale by reason of their location under the mining laws does not prevent the United States from treating such land as public land for the purpose of enforcing laws prohibiting persons from destroying evidences of or interfering with the making of public land surveys. *Destruction of Monument of Official Mineral Survey* (1938) 56 L.D. 291, 292.

[56] Oklahoma v. Texas (1922) 258 U.S. 574, 600.

[57] United States v. Sweet (1918) 245 U.S. 563 and acts noted in note 2, pp. 571-572. LINDLEY ON MINES, §§18, 20 and 81.

This practice began with the ordinance of May 20, 1785,[58] and was observed with great persistency in the early land laws.[59] While these early laws only specially and occasionally provided for the sale of mineral lands, they very generally evinced a purpose to reserve such lands for future disposal. This purpose was given particular emphasis following the discovery of gold in California in 1848, as is shown by the Oregon donation act, the homestead act (which adopted the mineral land reservation of the preemption act of 1841), the grant to the several states for the benefit of agricultural colleges, the railroad land grants and other land acts of that period.[60] These and other similar acts were but expressive of the will of Congress that every grant of public lands should be taken as reserving and excluding mineral lands in the absence of an expressed purpose to include them; and upon this theory both declarations were carried into the United States Revised Statutes as expressing a general and permanent policy, the first in enlarged terms as §2318, which provides that ''In all cases lands valuable for minerals shall be reserved from sale, except as otherwise expressly directed by law,'' and the other as §2346 which was more limited in scope.[61]

The conditions ensuing from the discovery of gold and other minerals in the western states and territories resulted in a general demand for a system of laws expressly opening the mineral lands to exploration, occupation and acquisition, and Congress, responding to this demand, adopted from 1864 to 1873 a series of acts dealing with practically every phase of the subject and covering all classes of mineral lands.[62] These and related acts were codified in a chapter entitled ''Mineral Lands and Mining Resources'' of the U. S. Revised Statutes. Taken collectively they constitute a special code upon that subject and show that they are intended, not only to establish a particular mode of disposition of mineral lands, but also to except and reserve them from all other grants and modes of disposal where there is no express provision for their inclusion.[63]

§2318 U. S. Revised Statutes reserves from sale ''lands valuable for minerals'' to be disposed of only under law expressly directing such disposition. §2319 declares that

> "All valuable mineral deposits in lands belonging to the United States . . . are . . . free and open to exploration and purchase, and the lands in which they are found to occupation and purchase. . . ."

[58] 10 JOURNALS OF CONGRESS (Folwell's ed.) 119.

[59] This policy caused the court to say in United States v. Gratiot (1840) 14 Pet. 526, 537: "It has been the policy of the government, at all times in disposing of the public lands, to reserve the mines for the use of the United States." See also United States v. Gear (1845) 3 How. 120, 130-131. The foregoing cases involved lands containing lead mines and a like practice prevailed in respect to saline lands. Morton v. Nebraska (1874) 21 Wall. 660, 669.

[60] These acts are noted at the bottom of pages 568 and 569 of 245 U.S.

[61] United States v. Sweet (1918) 245 U.S. 563, 567-570. It is interesting to note that the foregoing case involved a grant of school land to the State of Utah, which grant did not specially reserve mineral lands, but which the court held were nevertheless reserved by virtue of the general policy of Congress by implication to reserve mineral lands from general land grants. And yet in the case of Work v. Louisiana (1925) 269 U.S. 250, 255, decided only seven years later the Court held that in 1849 and 1850 when the school land acts there involved were passed "there was no settled policy of withholding mineral lands from disposal save under laws specially including them." While the opinion attempted to distinguish the holding from the diametrically opposite ruling in United States v. Sweet, *supra*, it only does so by ignoring the argument advanced in that case that the policy of tacitly reserving mineral lands from general land grants was initiated by Congress from the very beginning and continued in force thereafter without any cessation or break. The only possible ground for exception from this general rule is that Louisiana was not known to have mineral land of any particular consequence until petroleum and sulphur deposits were discovered there in more recent years and hence did not share in the general excitement which followed the discovery of gold in California in 1848. In fact, the court intimates that this situation did not apply to Louisiana because it was not known to be rich in minerals as was Utah. (258-259).

[62] *Ibid.* These acts are cited in note 1, p. 571.

[63] *Ibid.* at 571.

as provided by law. Many of the Acts of Congress providing for the disposition of public land expressly except ''mineral lands'' from their operation, so that it becomes important to determine what Congress intended by its frequent use of these words ''mineral lands.'' The Supreme Court of the United States (*Burke v. Southern Pacific Co.* (1914), 234 U.S. 669) says, referring to the mining, homestead, railroad land grant, and other public land laws: ''Evidently it has the same meaning in all,'' (677) and while no attempt had been made by Congress to define the words, ''doubtless the ordinary or popular signification of that term was intended.''

Not all lands which contain mineral are ''mineral lands'' within the meaning of the mining laws. Lands which contain mineral in such small quantities and of such low grade and value as to be worthless for mining, do not measure up to the statutory requirements. The question is always one of fact. There is no certain, well-defined, obvious boundary between mineral lands and those which cannot be classed in that category. It is clear that a ''paying mine'' is not essential to make land mineral in character. The land must be ''better adapted to mining'' than for other purposes. It must contain minerals ''in quantities sufficient to render it available and valuable for mining purposes, . . . to justify the expense of . . . . exploitation,'' and ''to justify expenditure for their extraction.'' It comprehends all lands ''chiefly valuable for their deposits of a mineral character, which are useful in the arts or valuable for purposes of manufacture.''[64] Mineral lands, as the phrase has been applied in the administration of public lands, embrace not only those which the lexicon defines as mineral, but, in addition, such as are valuable for other deposits, such as marble, slate, and even guano.[65]

''Agricultural lands'' are the descriptive words generally applied to lands that are ''non-mineral.'' The word ''agricultural'' is to be interpreted in the light of existing legislation and conditions. Congress has used it at times so that it is synonymous with ''land subject to be taken by preemptors or homesteaders under the public land laws'' and, under such circumstances, this designation would not include non-mineral lands valuable solely for timber or other uses which would not justify settlement under the applicable land settlement laws as contemporaneously understood and administered.[66] Nevertheless, it is quite common to describe lands as ''agricultural'' in an all-inclusive sense to distinguish them from and contrast them with ''mineral lands.''[67]

Minerals. We have seen that a serious and perplexing question oftentimes arises as to whether or not a tract of land contains sufficient indication of the presence of an admitted valuable mineral, such as gold or silver, etc., to justify characterizing the land as mineral land. We have an equally difficult problem to solve in determining in certain instances whether the very substance involved and found in the land in question may properly be called a ''mineral'' within the meaning of

[64] LINDLEY ON MINES, §§94-95; Burke v. Southern Pacific Co. (1914) 234 U.S. 669, 676. See Opinion of Land Department (1933) 54 L.D. 294, which states that if the mined material can be "marketed at a profit," the mining law is applicable.

[65] United States v. Northern Pac. Ry. Co. (1940) 311 U.S. 317, 361.

[66] *Ibid.* at 358-364.

[67] Christman v. Yonkers (1933) 54 L.D. 228, 230; Copper Belt etc. Mining Co. (1934) 54 L.D. 475, 480; Austin v. Mann (1937) 56 L.D. 85, 87. Lands will be considered mineral or agricultural as they are more valuable in the one class or the other, Lane v. Cameron (1916) 45 App. D.C. 404, reprinted in 46 L.D. 195.

See LINDLEY ON MINES, §97 and RICKETTS, AMERICAN MINING LAW, §11 for lists of substances held to be minerals by the authorities.

the mining law. It is obvious that some material restriction must be placed on the definition of mineral as so used in legislation because, in its broadest and most generic sense, mineral includes everything that is inorganic as opposed to the comparatively limited quantity of things belonging to the vegetable and animal kingdoms. Nearly all of the earth's land surface would, in the broad sense, be classified as mineral. At one time some of the courts were inclined to hold that the word "mineral," as used in the mining laws, was limited to metallic substances, but soon recognized their error and held that it was intended to apply to non-metallic substances as well.[68] Now it is generally recognized that any substance, other than organic, which possesses a special economic value for use in mercantile or commercial enterprises and in the arts and sciences, is a mineral within the contemplation of the mining laws. And, if this substance is found in the land in sufficient quantity and value to warrant a prudent man in the expenditure of time and money in the reasonable expectation of success in developing a paying mine, such land is disposable only under the mineral land law.[69] The extremely general nature of this test is indicative of the difficulties and uncertainties of the problem. As we approach the dividing line, juries, courts and experts will naturally differ as to whether the deposit should be classed as mineral or not. The greatest differences of opinion have arisen over deposits of sand, gravel, gypsum, cement rock, limestone, brick clay, granite and, in fact, all superficial deposits of low value, especially where the substance in question exists in large quantities and extends over considerable areas. Unless it has some unique quality and is confined to a comparatively limited area, so as to differentiate it from the surrounding country, and unless it can be shown to have some special quality making it valuable in manufacturing or in some of the arts and sciences, it is generally regarded as not meeting the test of "valuable mineral" and hence is not subject to acquisition under the mining laws. The Land Department has decided that many of the deposits above enumerated, and others of similar character, are not to be classed as mineral.[70] In

[68] LINDLEY ON MINES §96; Burke v. S. P. Co. (1914) 234 U.S. 669, 678.

[69] *Ibid.*, §98, p. 175; Cataract Gold Mining Co. (1914) 43 L.D. 248, 254. The Land Department rendered this decision in the form of "instructions" intended to cover the subject generally and it contains a comprehensive review of authorities bearing on the question. Its importance is emphasized by the fact that it has been cited in many subsequent departmental decisions. It reaches the conclusion that, if the lands can be shown to be "valuable for mineral," they come within the scope of the mining laws, "notwithstanding the fact that they may possess a possible or probable greater value for agriculture or other purposes." Of course, if the lands have a greater value for other purposes, a greater burden is correspondingly cast on the mineral claimant to prove present mineral value and future possibilities. However, many of the cases overlook the distinction above noted and state without reservation that the test is whether the land is more valuable as agricultural land or as mineral land.

[70] The following cases have decided adversely to the mineral character of the land involved:

Lands containing clay, sandstone and limestone, and not valuable for either, Gray Trust Co. (1919) 47 L.D. 18, 19-20. Lands containing common clay extending over large areas and not valuable for its alumina content, Hare v. French (1915) 44 L.D. 217. Ordinary brick clay, James C. Reed (1924) 50 L.D. 687, 689. Clay suitable only in cement manufacture and widely distributed, its value being only a small element of the cost of using it, Bettencourt v. Fitzgerald (1912) 40 L.D. 620. Shale used for a similar purpose, Victor Portland Cement Co. v. S. P. R. R. (1914) 43 L.D. 325. Deposits of low grade granite which exist for miles around and of no commercial value, Stanislaus Electric Power Co. (1912) 41 L.D. 655, 660. Shell rock existing in large quantities and used for road metal, Hughes v. Florida (1913) 42 L.D. 401, 402-3. Fossil remains of dinosaurs and other extinct animals are not minerals, *In re* Douglass (1915) 44 L.D. 325, 326. A limestone bed or lode deposit which could not be successfully mined at a profit, Big Pine Mining Corp. (1931) 53 L.D. 410, 412. Where assays showed negligible values in gold, silver and copper and mining costs would be high and no development in the vicinity ever resulted in the production of commercial ore. Opinion *in re* validity of mining claims in National Parks, *Challenge to Validity of Mining Claims in National Parks* (1931) 53 L.D. 491.

subsequent cases it has acted more liberally as to certain of these "borderline" deposits.[71]

In determining whether or not a substance is to be considered a mineral within the meaning of the mining laws "a strictly scientific test . . . is not the test contemplated by the statute." Instead, the statute "was dealing with a practical subject in a practical way. . . ."[72]

Since the Land Department has been charged by Congress with the disposition of public lands, it is preeminently its function, in disposing of them, to determine their character, not only as between rival and conflicting mineral and agricultural claimants, but also to classify them in the first instance with a view to such ultimate disposal. When a case involving a determination of the character of land is pending before the department, the courts usually will not interfere, but will suspend court proceedings awaiting such departmental determination. The department's decision on such questions of fact is treated by the courts as binding on them in the absence of other controlling factors, and they will seldom review its decisions on such questions.[73] On questions of law, the situation is otherwise, and the courts will review the Land Department's conclusions and does not hesitate to overturn them if not well founded.[74]

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[71] The following deposits have been held to be mineral and locatable as such:

Granite favorably situated for quarrying and having a value for building purposes. Micklejohn v. Hyde (1913) 42 L.D. 144, 145-6. See also Burke v. S. P. R. R. Co. (1914) 234 U.S. 669, 670. Diatomaceous or infusorial earth Central Pac. Ry. Co. (1916) 45 L.D. 223, 226. Trap rock suitable for railroad ballast and road metal where the rock can be extracted and used at a profit and the land has no other value. Stephen E. Day (1924) 50 L.D. 489, 491-493. Oil shale. Instructions (1920) 47 L.D. 548; also see Utah v. Watson Oil Co. (1924) 50 L.D. 323, 326, and Standard Shales Co. v. Summers (1927) 52 L.D. 201, 206. In the case of Layman v. Ellis (1929) 52 L.D. 714, the Land Department overruled Zimmerman v. Brunson (1910) 39 L.D. 310, and reviewing *in extenso* the literature and authorities on the subject, decided that gravel and similar substances which "can be extracted, removed and marketed at a profit" are minerals and subject to the mining laws. Affirmed and applied to sand. Opinion (1933) 54 L.D. 294. Pumice and volcanic ash. Bennett v. Moll (1912) 41 L.D. 584.

[72] Burke v. Southern Pacific Co. (1914) 234 U.S. 669, 679. In this case it was argued that petroleum had an organic origin and hence could not properly be classed as a mineral which supposedly must be an inorganic substance. In deciding that petroleum was "a mineral" the court used the language just quoted in the text. See Colby, *The Law of Oil and Gas* (1942) 30 CALIF. L. REV. 245, 247-250.

[73] LINDLEY ON MINES, §§95, 161, 207, 496, 664, 717; Cameron v. United States (1920) 252 U.S. 450, 460.

[74] *Ibid.*, §666; El Paso Brick Co. v. McKnight (1914) 233 U. S. 250, 257; Daniels v. Wagner (1915) 237 U.S. 547, 557, 561; Wilbur v. Krushnic (1930) 280 U.S. 306, 318; Ickes v. Development Corp. (1935) 295 U.S. 639, 647.

PUMICE AND PERLITE AS INDUSTRIAL MATERIALS IN CALIFORNIA*

By C. R. King**

OUTLINE OF REPORT

ABSTRACT

Pumice and perlite are acidic volcanic glasses. Pumice is a natural glass so vesicular that it resembles a froth. Perlite is a variety of obsidian which, when suddenly subjected to high temperature, will expand up to twenty times its original volume to form an artificial glass froth resembling pumice. This material is known as expanded perlite. Pumice has been used for hundreds of years as an abrasive and for a shorter period of time as an inert, light-weight aggregate. For nearly all present uses, expanded perlite can be substituted for natural pumice, and is a potentially important material in industries for which pumice is not suitable.

Deposits of perlite and pumice are widely distributed in California. The principal northern deposits are in Siskiyou and Modoc Counties; Lake, Napa, and Sonoma Counties are foremost in the central part of the state; and Mono, Inyo, Kern, San Bernardino, Riverside, and Imperial Counties in the south. Many of these deposits are being exploited for use in the abrasive and construction industries, and the quarrying, processing, and sale of these mineral products is an important and rapidly growing industry.

The processing of perlite and other types of expandable obsidian is, in the United States, a recently developed industry dating from about 1940. Furnace design, specifications, and marketing are phases of the new business still in the research or pilot-plant stage. However, technical data on these and other phases of the industry are rapidly accumulating.

ACKNOWLEDGMENTS

Most of the firms and individuals engaged in the aggregate, pumice, and fledgling perlite industries of the state, many independent consulting engineers, and the staff of the California Division of Mines, have cooperated in supplying data, ideas, and constructive criticism during preparation of this paper.

PUMICE AND PERLITE DEFINED

Pumice and perlite are acidic volcanic glasses produced from granite magmas during volcanic eruptions. They are essentially complex silicates of aluminum, potassium, sodium, calcium, magnesium, and iron, plus other minor constituents. Chemical analyses of most natural glasses

* Presented at the Non-Metallic Minerals Conference, American Institute of Mining and Metallurgical Engineers, Pacific Chemical Exposition, San Francisco Civic Auditorium, October 23, 1947.

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Table 1. Analyses of typical igneous rocks.

Type of rock	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Ignition loss
Typical normal granite, average of 546 analyses; all periods	70.18	13.49	1.57 FeO-1.78	1.99	0.88	3.48	4.11	-------	0.84
Typical rhyolite, average of 126 analyses	72.80	13.49	1.45 FeO-0.88	1.20	0.38	3.38	4.46	-------	1.47
Typical pumice, average of 80 analyses	70.38	15.82	1.50 FeO-1.42	1.56	0.48	3.70	4.10	-------	3.62
Typical obsidian, average of 41 analyses	73.84	13.00	1.82 FeO-0.79	1.52	0.49	3.82	3.92	tr.	0.53
Typical rhyolitic perlitic obsidian, average of 20 analyses	71.88	12.73	1.65 FeO-0.96	1.26	0.35	2.93	4.35	-------	3.84
Typical granodiorite, average of 40 analyses	65.01	15.94	1.74 FeO-2.65	4.42	1.91	3.70	2.75	-------	1.04
Typical dacite, average of 90 analyses	65.68	16.25	2.38 FeO-1.90	3.46	1.41	3.97	2.67	-------	1.50
Typical andesite, average of 87 analyses	59.59	17.31	3.33 FeO-3.13	5.80	2.75	3.58	2.04	-------	1.26
Typical diorite, average of 70 analyses	56.77	16.67	3.16 FeO-4.40	6.74	4.17	3.39	2.12	-------	1.36
Typical gabbro, average of 41 analyses	48.24	17.88	3.16 FeO-5.95	10.99	7.51	2.55	0.89	-------	1.45
Typical basalt, average of 198 analyses	49.06	15.70	5.38 FeO-6.37	8.95	6.17	3.11	1.52	-------	1.62

indicate that the constituents are present in the following proportions: silica, 65 to 75 percent; alumina, 9 to 20 percent; soda and potash, less than 8 percent; lime and magnesia, less than 3 percent; and iron oxide, less than 3 percent. Most analyses also show traces of manganese, titanium, phosphorus, and other oxides (see tables 1 and 2). Natural glasses are found only in association with young volcanic rocks because, in terms of geologic time, they are subject to rapid devitrification and alteration to clay-like materials.

Pumice is an acidic, vesicular, volcanic glass in which countless cells are formed by the expansion of gases within the semimolten rock during explosive volcanic activity. The chemical composition of pumice corresponds to that of rhyolite or dacite and is a granite magma derivative (see tables 1 and 2). Pumicite and volcanic dust are synonymous terms referring to finely comminuted vesicular acid lava produced by violent explosive volcanic activity. Chemically, pumicite is of the same range of composition as pumice. The difference between pumice and pumicite is one of particle size and is an arbitrary distinction. An accumulation, the fragments of which are pea size or larger, is known as pumice; one in which the fragments are smaller than pea size is termed pumicite. A mixture of coarse and fine fragments is called volcanic tuff or simply tuff.

Scoria is a basic, vesicular lava in which relatively large cells are formed by the expansion of gases during cooling of a semimolten mass. Chemically, scoria corresponds to andesite or basalt and is derived from a diorite magma.

Obsidian is an acidic volcanic glass of the same general chemical composition as pumice but without the highly vesicular structure

Table 2. Analyses of typical expanding obsidians.

Type obsidian and locality	SiO_2	Al_2O_3	MgO	CaO	Fe_2O_3	FeO	Na_2O	K_2O	H_2O —110	H_2O 105	TiO_2	P_2O_5	MnO_2	Total	Ig loss	Expan-sion temp°F
Perlite from New Zealand	74.73	10.82	0.20	0.80	2.46	0.58	2.68	4.40	2.94	0.27	0.12	0.12	0.03	100.15	-------	2200
Perlite from near Lordsburg, N. M.	70.31	12.08	-------	1.34	1.68	-------	3.09	4.25	2.18	-------	-------	-------	-------	94.93	6.16	2110
Perlite, Snowhite mine, Superior, Ariz.	73.41	12.34	-------	0.75	1.33	-------	2.95	5.33	3.70	-------	-------	-------	-------	99.81	3.70	1751
Perlite, Rheem mine, Superior, Ariz.	73.61	12.17	-------	0.84	1.51	-------	2.97	5.08	3.34	-------	-------	-------	-------	99.52	3.36	1904
Vitrophyre, Yucca, Ariz.	72.21	12.03	-------	1.04	2.67	-------	2.76	5.26	2.34	-------	-------	-------	-------	98.31	2.30	2030
Obsidian, near Superior, Ariz.	74.90	12.19	-------	0.78	2.37	-------	3.62	4.65	0.61	-------	-------	-------	-------	99.12	0.55	2102
Perlite, near Goodsprings, Nev.	70.63	13.36	-------	1.69	2.23	-------	2.93	5.16	2.84	-------	-------	-------	-------	98.84	2.30	1949
Vitrophyre, near Beatty, Nev.	72.20	12.49	0.70	0.75	3.19	-------	2.60	5.60	1.47	-------	-------	-------	-------	99.00	1.20	2000
Perlite, Deschutes River, Oregon	67.05	14.91	0.65	2.44	0.92	1.48	4.15	3.04	4.35	0.50	0.34	0.12	tr	99.95	-------	1400
Perlite, Lady Francis mine, Oregon	73.79	12.40	0.11	0.80	0.52	0.62	3.16	4.84	3.24	0.25	0.09	0.01	0.02	99.85	-------	1700
Obsidian, Napa Co., California	72.56	15.87	0.13	1.56	1.81	-------	3.80	3.80	0.19	-------	-------	-------	-------	99.72	0.28	2400
Obsidian, Lake Co., California	71.32	18.55	0.33	1.58	1.81	-------	3.00	3.15	0.15	-------	-------	-------	-------	99.89	0.26	2400?
Perlite, near Alturas, California	74.82	13.61	0.04	0.68	0.25	0.89	1.98	2.99	3.86	0.22	0.28	-------	0.04	99.66	-------	2200?
Perlite, near Aguila, Ariz.	73.00	15.80	tr	1.70	1.00	-------	2.00	2.24	3.99	0.18	-------	-------	-------	99.91	-------	2300?
Perlite, near Newberry, California	70.40	16.28	tr	1.60	1.27	-------	1.20	2.66	5.98	0.22	-------	-------	-------	99.61	-------	2000?
Perlite, Turtle Mts., California	74.00	15.60	0.01	3.80	1.50	-------	comb.	2.40	-------	-------	-------	-------	-------	98.31	2.69	-------

Table 3. United States and California production of pumice and pumicite.

Year	Tons produced			Total value			Value per ton	
	United States	California	California, percent of total prod.	United States	California	California, percent of total value	United States	California
1930	56,843	12,947	23	$336,000	$128,847	39	$5.91	$9.95
1931	68,819	11,711	17	338,586	108,130	32	4.92	9.23
1932	53,214	9,891	19	235,204	86,034	37	4.42	8.70
1933	61,220	8,243	13	241.834	61,067	25	3.95	7.41
1934	56,169	9,951	18	207,058	54,748	26	3.68	5.50
1935	60,000	14,890	25	247,000	87,055	35	4.12	5.84
1936	72,915	17,132	23	328,406	143,709	44	4.50	8.39
1937	71,007	10,392	14	301,936	79,005	26	4.25	7.60
1938	65,742	18,783	29	312,886	105,207	34	4.76	5.60
1939	89,159	41,109	46	424,780	159,951	38	4.76	3.90
1940	82,407	35,162	43	499,914	126,516	25	6.06	3.60
1941	117,310	85,309	73	669,514	283,663	42	5.70	3.32
1942	126,522	74,925	59	706,199	206,424	29	5.60	2.75
1943	85,150	25,490	29	611,495	160,441	26	7.18	6.29
1944	88,757	31,409	35	704,110	245,898	35	7.93	7.83
1945	157,011	89,209	56	1,051,037	461,022	44	6.69	5.17
1946*	-------	109,191	-------	-------	540,811	-------	-------	4.95

* 1946 statistics for United States not available. California production is for pumice and pumicite.

exhibited by pumice. Obsidian is derived from an acid or granite type magma and forms by rapid ejection and cooling in the shape of flows, dikes, or sills. Tachylite is the basic counterpart of obsidian.

Perlite is a variety of obsidian characterized by concentric, shelly, or spherulitic structure; waxy to pearly luster; conchoidal, splintery, or columnar fracture; and the presence of considerable amounts (2 to 5 percent) of combined and uncombined water.

Expanded perlite (or other varieties of obsidian subject to heat expansion) is a synthetic or man-made pumice, the vesicular structure of which is formed in a furnace under controlled conditions instead of by the blind natural forces under which natural pumice forms.

All natural acid glasses fall within a specific gravity range of 2.3 to 2.5; have a silica plus alumina content of more than 80 percent; exhibit a pearly to glassy luster; contain 0.1 to 5.0 percent total combined and uncombined water; range in color through gray, green, reddish brownish or black; have a conchoidal, splintery, or columnar fracture; and are always transparent or translucent when in small fragments. Heat decreases the viscosity in direct proportion to the temperature.

INDUSTRIAL USES OF PERLITE AND PUMICE

Pumice has been used for many purposes since the time of the Romans. It has long been a standby of the abrasive industry as a polishing agent; of the construction industry as a light-weight aggregate for use with lime mortar, portland cement, and other binders; and as an ingredient of pozzuolanic cements. In these cements, the aluminum silicate supplied by pumice forms compounds which result in increased resistance to salt and fresh water penetration and corrosion. Concrete made with pozzuolanic cement continues to harden for a long period of time.

The extensive use of pumice in industry for non-abrasive purposes, in California and the United States, dates from about 1925. In 1926, the California production of pumice and pumicite was 7,170 tons, valued at the quarries, at $48,350. This was used almost entirely by the abrasive

industry. By 1946 the California production of pumice and pumicite had increased to 109,191 tons, valued at $540,811 at the quarries. More than 90 percent of the 1946 production was used in the building industry as an aggregate, and production is still increasing (see table 3).

The first attempts to make and use expanded perlite in the United States date from about 1940, although this material had been in use in Germany prior to 1925. The industry, in this country, is still in the throes of technical and market research but will probably become of major importance in California and other western states. To date, no production data and very little specific information on processes, standards, and techniques are available. It is probable that within a few years, expanded perlite will largely supplant natural pumice for industrial use and will be used in many new products where natural pumice would be unsuitable. Technical and market research upon perlite is proceeding rapidly, and adequate standards and specifications governing processing and use of expanded perlite are being evolved. Competition may be expected to stabilize a price structure below the present selling price. Such stabilization would put expanded perlite into a competitive position with other materials from the standpoint of cost as well as usefulness. There is no question as to potential industrial value of an inert mineral material that can be shipped from almost inexhaustible deposits into centers of consumption in the form of a heavy, crude rock subject to low freight schedules, and in such centers converted into extremely lightweight, uniform products tailored to a wide variety of uses. Perlite and other expandable obsidians are just such materials.

Pumice and Expanded Perlite as Abrasives

Ground pumice and pumicite are used extensively as ingredients in soaps and cleansing compounds where an abrasive additive is required. Material for this use must be free from sharp, gritty, particles of silica or other impurities and from alteration products such as bentonite. Color is an important consideration especially when the material is used in cleansers. Cleanser material should be white when wet as well as when dry. In fine-polishing operations, the chief value of ground pumice lies in the shape of the particles. These are either thin curved fragments such as would be formed by the shattering of a thin-walled glass sphere or fragments of hollow, silky fibers. These particle shapes persist even through continual disruption into smaller particles during use. The particle shape and hardness (about 6 on the Mohs scale) of pumice, pumicite, and expanded perlite make them indispensable in certain polishing operations. Certain types of expanded perlite are superior to natural pumicerous materials for some abrasive uses, as expanded perlite can be made more uniform in all physical properties and is snow white in either wet or dry form.

Pumice and Expanded Perlite as Aggregates

In concrete and plaster, whether poured, applied manually, or used as precast masonry shapes, pumice of suitable characteristics and expanded perlite of the proper type make excellent aggregates. Pumice and expanded perlite aggregates have the following advantages: (1) light weight of finished wall or unit (from one-fourth to two-thirds the weight obtained when sand and rock aggregate is used); (2) very high strength to weight ratio in finished wall or unit (from 20 to 40, as com-

Table 4. Size range of commercial abrasive grades of ground pumice.

Mesh	Commercial designation or number														Mesh
	−14 +30	No. 3	No. 2	No. 1½	No. 1½XX	No. 1	No. ½	0-¾	0-½	0	F	FF	FFF	FFFF	
On 16	22.92														On 16
30	75.66	.20	Tr.												30
40	.98	56.90	6.90	.85											40
50	.41	37.36	68.60	58.74	.10	11.00	Tr.	Tr.							50
60		3.04	19.80	28.94	29.50	44.40	.50	.04							60
70		.90	3.00	5.41	29.50	34.50	13.30	1.00	.06						70
80		.40	.40	2.20	13.20	5.90	25.10	.24	.10						80
100		.40	.40	2.60	17.60	3.40	45.20	7.10	2.60	.10	.11				100
120		.20	.40	.70	2.30	.10	4.50	24.42	7.50	.40	.08				120
150		.10	.10	.30	2.00	.10	3.20	41.60	15.80	6.90	.40	Tr.			150
170		.40	.10	.04	5.80	.10	.80	10.22	5.50	10.70	3.40	.10			170
200		.10	.07	.07		.10	.60	14.22	23.20	18.20	5.80	1.80	.30	.20	200
325			.20	.05		.10	.40	0.85	13.80	24.50	24.80	23.00	16.00	13.40	325
−325				.04		.10	6.40	.27	31.44	39.20	64.41	75.10	83.70	86.40	−325
**	−14 +30	−30 +45	−35 +50	−40 +60	−45 +80	−45 +70	−60 +100	−100 +150	−100 +170	−150 +200	−100	−150	−200	−300	

** These figures indicate mesh screens used in producing respective grades.
—30 +45 means through 30 mesh and on 45 mesh screen, etc.

pared with 15 to 20 for standard concrete); (3) great resiliency and resistance to shock or to movement within the structure; (4) little tendency to crack or shatter under impact; (5) excellent bonding properties with most binders; (6) very great resistance to fire or chemical attack; (7) high value as insulating mediums (from two to ten times equivalent values obtained with sand and gravel aggregates); (8) inertness with respect to attack by insects, fungi, and most chemicals; (9) workability (can be sawed, nailed, and perforated without cracking, spalling, or splintering), and consequent saving of labor during construction or application; (10) less tendency to "sweat" or condense moisture than ordinary concrete or plaster when used in aggregates in walls (see table 5).

Pumice and expanded perlite have some disadvantages as aggregates, chief among which are the following: (1) somewhat higher cost per yard and in some cases lower yields than sand and gravel; (2) somewhat higher moisture absorption and volume change than sand and rock aggregate concrete; (3) lower compressive strength than can be obtained by the use of sand and rock aggregate. If strength per unit weight is considered, however, pumice or expanded perlite aggregate will compare favorably in compressive strength with sand and rock aggregate. Lack of standards and information governing specifications for material used, lack of mix formulae and techniques of application or use, and lack of precise data upon all properties of specific concretes or plasters using these aggregates, also are disadvantages to be overcome. All of these data are necessary before engineers and architects will be able to fully utilize the inherent advantages of these materials in structural design.

Where compressive strength is a major factor in structural or precast concrete, and light weight coupled with high insulation value of the finished wall is not important, the use of expanded perlite as an aggregate in concrete is not advantageous. Where compressive strength higher than about 2,500 pounds per square inch is necessary coupled with reasonably light weight and good insulating properties in the finished concrete, other lightweight aggregates such as a good grade of pumice or rocklite (or similar bloated shales) will in most cases be more suitable from all standpoints than expanded perlite. High strength concretes can be made with expanded perlite aggregate (see table 13) but, generally speaking, the yield is lower and mix must be richer than in the case of structurally stronger lightweight aggregates selling in about the same price range or lower.

Where light weight (below 75 pounds per cubic foot of finished concrete), high insulation value (below a "k" factor[1] of 2), and great resistance to fire (less than 200 degrees fahrenheit temperature rise under 4-hour Underwriters Laboratory fire test of 4-inch thick panels) are wanted plus a compressive strength of between 1000 and 2000 pounds per square inch, the use of expanded perlite aggregate in concretes designed for specific uses, such as precast curtain wall panels for steel buildings or masonry or panel units for house construction, is advantageous. Table 6 details the relation of density, water absorption and "k" factor to compressive strength in concretes made from a typical expanded perlite.

As various methods of mass assembly and fabrication of dwellings are evolved, particularly in California, a great many new uses and a

[1] See table 6.

Table 5. Comparative table of some standard and lightweight aggregate concretes.

Type of aggregate	Cement to aggregate by vol.	Water cement ratio	Density, lbs./cu. ft. As poured	Density, lbs./cu. ft. 28 day air dry	Strength to wt. ratio	Comp. strength 28 day psi.	"k" factor	Water absorption, lbs./cu. ft.
Sand and crushed rock[1]	1:4.5	0.6	220	150	20.0	3,000	12.00	8.00
Sand and gravel[2]	1:6	0.7	225	150	16.7	2,500	12.00	10.00
Rocklite (bloated shale) aggregate[3]	1:3.2	0.7	175	120	48.2	5,800	5.75	10.00
Rocklite, as above[4]	1:5.6	0.7	175	93	27.2	2,530	3.42	12.00
Pumice[5]	1:3.9	0.85	?	105	28.6	3,000	2.20	14.00
Pumice[6]	1:3.9	0.85	?	72	27.8	2,000	2.00	16.00
Pumice[7]	1:6	0.90	?	60	16.7	1,000	1.85	18.00
Perlite, 12 lbs. bulk density[8]	1:2	0.80	74	66	37.9	2,500	1.87	14.20
Perlite, as above[9]	1:4	0.85	58	47	25.6	1,200	1.40	14.20
Perlite, as above[10]	1:8	0.90	49	32	10.5	336	1.02	16.70
Perlite, 11 lbs. bulk density[11]	1:5	0.70	--------	94	79.9	7,000	2.77	13.00

[1] Standard 1:2:4 mix using siliceous aggregate. Used for structural concrete, in plastic mix.
[2] Standard 1:2:4 mix as used for precast masonry.
[3] Rocklite, (a bloated shale aggregate), plus 63 percent (by weight) sand in the mix; plastic concrete for structural work.
[4] Same as note 3, except 29 percent sand in mix; non-plastic for precast masonry concrete.
[5] Pumice mix contains 45 percent sand; plastic optimum strength concrete for structural use.
[6] Pumice plastic structural concrete; no sand used in mix; optimum insulation with good strength and low weight.
[7] Pumice concrete for precast masonry and insulation panels and slabs; non-plastic, minimum weight, maximum insulation.
[8] Perlite concrete, optimum strength non-plastic for precast masonry units; or plastic if plasticiser added, for structural.
[9] Same as above, best compromise for strength, insulation, and light weight. Precast masonry units, non-bearing curtain wall panels, etc.
[10] Same as above, for high insulation and light weight where strength is not important.
[11] Gunite applied perlite concrete, 10 percent sand in the mix; this "pressurized" type perlite concrete has excellent properties where very high compressive and tensile strengths are more important than yield, which is relatively low. Extremely high strength to weight ratio is obtained by gunite application in making panels, walls, etc.

5A. Relation of "k" factor to compressive strength and density of concrete.

Water absorption, lbs./cu. ft.	Cement-aggregate ratio	Density, lbs./cu. ft. As poured	Density, lbs./cu. ft. 28 day	Comp. strength 28 day	"k" factor
14.2	1:2	74	66	2,564	1.87
17.1	1:3	63	54	1,574	1.65
14.2	1:4	58	47	1,149	1.40
15.4	1:5	55	41	654	1.23
15.6	1:6	51	37	477	1.18
16.8	1:7	50	35	389	1.11
16.7	1:8	49	32	336	1.02
17.6	1:9	47	30	212	0.918
16.7	1:10	46	29	141	0.904
18.7	1:11	46	27	70	0.794
18.7	1:12	45	26	35	0.763

Table 5B. "K" factor of vibrated loose fill perlite insulation of varying bulk densities.

Bulk density lbs./cu. ft.	"k" factor
4.88	0.267
6.00	0.324
8.50	0.345
11.00	0.450

NOTE.—Method of packing was by vibration until no further settling was noted.

When used as loose fill insulation without packing, and using a perlite of 2.5 to 3.0 lbs./cu. ft. bulk density, the "k" factor ranges from 0.20 to 0.22.

Table 6. Screen analysis of perlite plaster aggregate.

On mesh	Percent	On mesh	Percent
4	0.0	50	28.8
8	0.3	100	14.2
16	8.9	–100	7.4
30	40.4		

rapidly growing demand for concrete prefabricated masonry units of various types in the weight range of 40 to 75 pounds per cubic foot may be expected. For this type of concrete, expanded perlite aggregate is entirely suitable.

When cost of finished building is taken as a measure in comparing relative cost of aggregates used in the concrete, pumice aggregate in many cases is cheaper than sand and gravel aggregate. An example is the new building of the Los Angeles Telephone Exchange at Fifth and Grand Avenue, Los Angeles. The total cost of this building was $1,600,000. Using rock aggregate, the cost of concrete would have been $38,920, or 2.4 percent of the cost of the building. The pumice-aggregate concrete cost $59,720, which was 3.7 percent of the cost of the building or $20,800 (1.3 percent of the total cost) more than in the case of rock aggregate. However, owing to weight advantages, 300 tons of steel were saved, which, at $130 per ton, was $39,000. Thus an overall saving of $18,200 resulted from the use of pumice aggregate in this building, plus the additional advantages of better insulation properties of the walls and greater resistance to earthquake shocks. The use of pumice aggregate in the average small dwelling will not show an appreciable saving in total cost, but, on the other hand, will cost little, if any, more than conventional aggregate, and the net result of the use of pumice or expanded perlite aggregate is a better wall at about the same cost.

Pumice aggregate is advantageous in concrete suitable for use in the Tournalayer system of mass production of concrete houses where a quick-setting, lightweight concrete of about a 4-inch slump is required. The use of this system, where the enormous ''Tournalayer'' machine picks up an entire house after casting and travels to the site where the house is deposited, is ideal for rapid mass construction of uniform dwellings. Condensed data from use of one type of Coso pumice aggregate with the Tournalayer system can be seen in table 7. Coarse aggregate and fine aggregate of the screen analyses (shown in table 8) were mixed 37.5 percent coarse and 62.5 percent fine, by weight. Weight of mixed aggregate approximated 1100 pounds per yard. One yard of concrete was secured by the use of 420 pounds of coarse aggregate and 700 pounds of fine, plus 611 pounds of Monolith Hi-Tensile cement. Water-cement ratio was 0.8 to 0.85 to get a 4-inch slump, a good plastic mix with little bleeding, and good compacting in the large vibrated mold. This mix, as used, consistently gives a 28-day pounds-per-square-inch in compression of more than 2,000, with tensile strength about 10 to 15 percent of compressive strength. Early strengths are important, for the houses are moved in the outer mold after only 16 hours setting time. The following early strengths are secured by use of the foregoing mix: 12 hours, 500 pounds per square inch; 14 hours, 600 pounds per square inch; and 16 hours, 800 pounds per square inch. Weight of the complete 24- by 32-foot house, including footings, roof, and one central

Table 7. Comparative characteristics of rock aggregate and good pumice aggregate.

Compressive psi wanted	Unit weight lbs./cu. ft.		Cement ration sacks/yard		"k" factor*	
	Pumice	Rock	Pumice	Rock	Pumice	Rock
3,500	110	155	7.5	6.5	2.25	13.00
3,000	102	152	7.0	6.0	2.20	12.50
2,500	90	150	6.5	5.5	2.15	12.00
2,000	87	148	6.0	5.0	2.00	11.50
1,500	75	145	5.0	4.0	1.95	11.00
1,000	66	142	4.5	3.5	1.85	10.50

* "k" factor (thermal conductivity) is expressed as: British thermal units per square foot, per hour, per inch thickness, per degree fahrenheit temperature difference between the two sides.

Table 8. Screen analysis of one type of Coso pumice aggregate.

Coarse aggregate		Fine aggregate	
On mesh	Cumulative percent	On mesh	Cumulative percent
1″	0.0	3/8″	0.0
¾″	18.0	4 mesh	8.0
½″	70.0	8 mesh	44.0
3/8″	97.0	14 mesh	59.0
Thru 3/8″	3.0	28 mesh	75.0
		50 mesh	83.0
		100 mesh	89.0
		thru 100	11.0

Note: 37.5 percent coarse mixed with 62.5 percent fine aggregate for use.

Table 9. Screen analysis of a typical Laws aggregate as prepared for use in the Van Loon panel machine.

Mesh size	Percent of the coarse aggregate increment	Percent of fine aggregate increment	Percent of composite aggregate as used	Cumulative percent
¾ inch	0.0	0.0	0.00	0.0
½ inch	4.3	0.0	2.15	2.1
3/8 inch	23.2	0.0	11.60	13.7
4 mesh	55.5	0.0	27.75	41.5
10 mesh	14.2	14.2	14.2	55.7
20 mesh	0.2	21.1	10.65	66.3
30 mesh	0.0	11.2	5.60	71.9
50 mesh	0.0	12.6	6.30	78.2
80 mesh	0.1	8.5	4.30	82.5
100 mesh	0.1	3.2	1.65	84.2
200 mesh	0.9	12.6	6.75	90.9
—200 mesh	1.5	16.6	9.05	100.0

Table 10. Chemical analysis of typical sample of Laws aggregate.

	Percent		Percent
SiO_2	76.56	Na_2O+K_2O	2.43
Al_2O_3	10.59	Ig. loss	4.42
Fe_2O_3	1.63	SO_3	3.04
MgO	0.06		
CaO	1.65	Total	100.38

partition, ranges from 38 to 42 tons depending on the number and size of door and window openings. The air-dry density of this concrete is about 73 pounds per cubic foot.

A typical high-grade pumice aggregate with strong pozzuolanic properties is mined from two deposits near Laws, Inyo County, California. The first is a wind-laid deposit of lump pumice ranging from 2 inches down to a quarter of an inch in size, very little fine material present. This deposit is in the form of an unconsolidated bed 4 to 5 feet thick with little or no overburden. The pumice is pure white in color. The second deposit is a bed of pumicite about 20 feet thick, overlain by a few feet of overburden. The two types of material are mixed in approximately equal proportions by weight after the plus one inch oversize has been crushed. The dry bulk-density of this material is: coarse, 38.4 pounds per cubic foot or 1,075 pounds per cubic yard; fine, 63.1 pounds per cubic foot or 1,768 pounds per cubic yard; 50-50 mix as used, 50.75 pounds per cubic foot or 1,370 pounds per cubic yard. For use in the Van Loon panel machine, which extrudes hollow building panels 2 by 9 feet in size, the 50-50 aggregate mixture requires 3.6 sacks of portland cement per cubic yard of mix. A ''harsh'' or zero-slump mix is used, and the machine vibrates to aid settling and compaction of the concrete. This concrete gives a compressive strength of 2,000 pounds per square inch in 28 days, and 2,750 pounds per square inch in 150 days. It weighs 80 pounds per cubic foot. Screen and chemical analyses of Laws aggregates are shown in tables 9 and 10.

The pozzuolanic or age hardening effect on concrete of certain pumices and pumicites has been very briefly mentioned. Where pozzuolanic concretes are wanted, the direct replacement of part of the cement used in the mix with some types of pumice fines (—200 mesh) or pumicite results in a marked increase with time in compressive strength of the concrete. Use of pumice fines also results in less permeability to water; and greater corrosion-resistance to sea water, fresh water, and organic acids; and reduction of volume change caused by alkali-aggregate reaction.

In the construction of the Los Angeles aqueduct from the Owens Valley to Los Angeles, pumice from the Laws and Coso districts was ground and added to the cement used in concrete for lining about 100 miles of the aqueduct. The ground pumice was used to replace from 25 to 50 percent of the cement in the concrete mix. The use of this material was partly based on tests made on 30 ''breaks'' on blended Monolith cement and Fairmont ground pumice (blended 50 percent by volume with cement and mixed one to three with Ottawa sand) (see table 11). Pumice was considered as part of the cement.

Tests made using pumicite from Lassen County as a substitute for part of the cement in a mix using standard sand and rock aggregate are summarized in table 12.

The comparative resistance of concrete to 5 percent acetic acid with and without pumicite partly replacing the cement was determined in the tests summarized in table 13.

The admixes used were four types sold for increasing the resistance of concrete to attack by acids, and were used in the proportions recommended by the manufacturer. The age-hardening effect is not demonstrated in the table of compressive strengths, because the test period was only 90 days. Reference to table 11, which shows results of tests

Table 11. Test data on Los Angeles aqueduct concrete.

Age	Compressive psi	Age	Compressive psi
3 days	152.0	6 months	538.1
7 days	248.5	1 year	546.0
28 days	421.2	5 years	643.2
3 months	491.0		

Table 12. Test data on pumicite-cement concrete.

Percent pumice by wt. replacing cement	Cement-agr. ratio (inc. pumicite as cement)	Comp. strength, psi			Slump, in.
		7 day	28 day	90 day	
None	1:6	2,075	4,390	4,600	5¼
10	1:6	2,065	4,225	4,580	4¾
20	1:6	2,360	3,570	4,685	4½

Table 13. Comparative values of admixes in increasing acid resistance of concrete.

Type of concrete	Compressive strength, 28 day, psi	No. cycles acid bath before failure
No admix-untreated	4,030	1
Admix No. 1	3,195	¾
Admix No. 2	4,000	2
Admix No. 3	3,240	1.5
Admix No. 4	3,345	1.5
Pumicite, 15% cement	3,555	No failure after 3 cycles

made for the Los Angeles aqueduct, shows that age hardening takes place slowly and begins to be noticeable after 6 months. This age hardening can be accelerated by steam curing to the point where nearly the full effect can be brought out in about 36 hours of steam treatment followed by 28 days of air curing.

All pumice and pumicite is not of value as a pozzuolanic agent. In general, the high silica pumicites and pumices are pozzuolanas, when no alteration whatever has taken place and the material is very finely vesicular (even under the microscope). A pozzuolan has been defined as "any form of silica or alkaline silico-aluminate which, when placed in the presence of slaked lime and water, will slowly combine with calcium hydrate, to form a low-lime calcium-silico-aluminate hydrate which exhibits slowly progressive dehydration and continuously increasing cementing value." Practically, the value of many materials as pozzuolanas is much overrated, and the only good procedure is to try various types in the particular mix for the specific use in mind.

One of the large potential markets for expanded perlite in California is as an aggregate in interior hardwall plaster, for which use it is superior to pumice. To date, very little definite useful information is available on the best types of expanded perlite or on the best mix formulae and techniques of application for this use. Los Angeles and most other city building codes make no provision for the use of this material in plaster aggregate at present and generally rule that in screen analysis it must conform to that used for plaster sand, that is, A.S.T.M. spec.

C-35-39 (see table 14). This may or may not be the best screen analysis for perlite plaster aggregate. It certainly is not from the standpoint of full utilization of the acoustic properties of such a plaster.

The following data apply to perlite used as plaster aggregate in these buildings: Western Merchandise Mart, San Francisco; building at 965 Mission Street, San Francisco; the Mapes Hotel, Reno, Nevada; and many dwelling units in Reno and the San Francisco Bay region. The expanded perlite used had the following properties: Color, gray with dark specks; apparent specific gravity, 95 percent floated on water; volume as sold, 3.3 cubic feet per sack; bulk density, 12 pounds per cubic foot; screen analysis, see table 6; water absorption, 32 percent (by method described under "control of physical properties of perlite"). Some advantages over sand aggregate are:

Weight Saving. Per 100 square yards of standard three coat, ⅝-inch plastered surface, substitution of perlite for sand aggregate results in a weight saving of from 2,000 to 4,000 pounds, depending on the mix used and experience of the plasterers with the material.

Labor Saving. A little more than 24 man-hours per 100 square yards of finished plastered wall (applied on wood lath) were noted by one contractor in the case of ordinary sand plaster. On the same basis, and under identical conditions, this contractor found that perlite aggregate plaster required 12.4 man-hours per 100 square yards of finished wall, a net saving of a little more than 12 man-hours per 100 square yards.

Insulation Value. The "k" factor of perlite aggregate plaster ranges from 0.4 to 0.8, depending on the mix and method of application. The "k" factor of sand aggregate plaster is from 3.00 to 3.50 depending on mix and method of application. Practically, this means that perlite aggregate plaster is about four to seven times better as a heat insulating medium than sand plaster.

Shock and Strain Resistance. No definite comparison standards for shock and strain resistance are available. There is no doubt that perlite aggregate plaster may be strained by nailing or by movements of the building, with less tendency to crack, chip, or spall than sand plaster. However, tests should be made in order to get definite comparisons with sand plaster.

The base upon which perlite aggregate plaster is used affects the mix. In general, the lean mix used with perlite aggregate and the fact that perlite plaster dries out much faster than sand plaster, require a moisture-retaining base such as concrete or masonry; tempering the mix with sand; or sprinkling after finishing in order to keep water in the mix long enough to get a good set. The proper setting time can of course be regulated by the use of accelerators where it is not desirable to use sand tempering or sprinkling. In general, in order to get a good fat mix, a little more water is required with perlite plaster than with sand plaster. Perlite plaster "goes on" much easier than sand plaster and should not be worked as heavily. Longer strokes are used. Perlite plasters have been used in mixes ranging from 1:7 hardwall to perlite (bulk ratio) on concrete or masonry base to 1:1 for hard finish coat. One plaster contractor states that for expanded metal lath, wood lath, or most other applications, the best mix is 1:4 (hardwall to perlite, by volume). This should be mixed to good consistency (using a little more water than with sand) and then applied with very little working. For

Table 14. Typical size grading of pumice and perlite aggregates.

Designation	Cumulative percent on mesh (Tyler standard screens)														
	¾″	5/8″	½″	3/8″	4M	8M	10m	16m	20m	30m	50m	80m	100m	200m	—200m
A.S.T.M. for (C35-39) light aggregate plaster, maximum on mesh						10.0				80.0	95.0				5.0
Minimum on mesh						0.0				15.0	70.0				
Perlite, Snolite aggregates for plaster	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0		48.0	82.5		94.5	(—100:5.5)	
Perlite, prefab. wall panels, concrete	0.0	0.0	0.0	0.0	0.0	0.3		9.2		49.6	78.4		92.6	(—100:7.4)	
Perlite, C.B.M. for gunite concrete	0.0	0.0	0.0	0.0	0.0	1.0		11.0		47.0	77.0		93.0	(—100:7.0)	
Perlite, acoustic plaster aggregate, coarse finish				0.0	0.0	51.1				98.5				(—100:1.5)	
Fine finish	Closely	sized all t	hrough 6	mesh on	12 mesh										
Pumice, plastic structural concrete	6.3		25.8	35.9	42.0	64.5		74.5		84.5	88.9		92.6	(—100:7.4)	
Pumice, O-slump, extruded concrete aggregates	0.0		2.1	13.7	41.5		55.7		66.3	71.9	78.2	82.5	84.2	90.9	9.1

a hard white coat, use of perlite instead of sand (about 20 percent by volume up to equal parts with hardwall) gives excellent results. For acoustic plaster, perlite aggregate sized closely (—12 mesh plus 30 mesh is one recommended sizing) and mixed 1 hardwall to 6 perlite is effective. The mixes used in the Mapes Hotel, Reno, Nevada, are:

Brown coat, over tile: 12 shovels Snolite (perlite), 16 shovels sand, 1 sack hardwall plaster.

Scratch coat, over metal lath or rock lath: 11 shovels Snolite, 11 shovels sand, 1 sack hardwall plaster.

White coat: Use Snolite instead of sand; Snolite averages 15 to 20 percent of mix (by volume).

Outside stucco: 3.5 cubic feet Snolite, 1 sack cement, 0.5 cubic feet hydrated lime, 1.7 cubic feet sand and a handful of hemp fibre.

In the San Francisco area, many contractors use perlite and sand together in interior plaster mixes, with sand to perlite ratios ranging from 1:1 to 1:4, and aggregate to plaster ratios from 3:1 to 7:1 (all ratios by volume).

The advantages in favor of expanded perlite as plaster aggregate apply to pumice, but to a lesser extent. In the case of interior plaster, the greater uniformity and lighter weight of expanded perlite of the proper type will probably result in this product largely supplanting pumice as an aggregate. At the present time, however, ground and sized pumice is in extensive use as a plaster aggregate, especially as an ingredient in acoustic plasters. The following closely sized grades of pumice acoustic aggregate are made by the Pacific Coast Pumice Company, Bishop, California (grades refer to screen sizing, top figure is mesh at which all passes, bottom figure mesh on which all is retained): 8/12; 8/20; 8/30; 8/40; 10/20; 10/30; 10/40; 14/28; 14/30; 18/35; 20/30; and 20/40. For use as acoustic aggregate, it is important that the size range be controlled within close limits.

The "k" factor of pumice aggregate hardwall plaster ranges from 0.8 to 1.75 (depending on mix and method of application) compared to 0.4 to 0.8 for perlite aggregate plaster and 3.00 to 3.50 for sand aggregate plaster. The weight saving over sand aggregate plaster when a good grade of pumice aggregate is used will vary between 900 and 1,800 pounds per 100 square yards of finished three-coat plaster depending on the mix used and whether or not some sand is used in the mix. There are no precise data on labor saving when pumice plaster instead of sand plaster is used. Pumice aggregate plaster undoubtedly "goes on" more easily than sand plaster, but it is not as light in weight nor as easily applied as perlite aggregate plaster.

Pumice and Expanded Perlite as Insulation Materials

Pumice and particularly expanded perlite are equal to any structural insulating material and superior to most. Expanded perlite of the proper type is much superior to pumice in this respect. The chief advantages of these materials as a bulk loose fill or (with a binder) as prefabricated shape insulation are: low "k" factor, as low as 0.22 in the case of perlite; very great resistance to fire or chemical attack; immunity to insect attack; no absorption of odors; very low moisture or gas absorption; light weight compared to most other insulating materials; very little tendency to disintegrate or pack when used as bulk loose fill insulation; and no tendency to decompose or react with binders or materials with which they are in contact.

Table 15. Analyses of typical pumice.

Type and locality	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Ignition loss
Lump pumice, Island of Lipari, Italy (high pozzuolanic)	73.0	13.0	3.0	1.00	0.35	3.60	4.50	-------	1.25
Wind-laid lump pumice, north of Laws, Calif., sec. 1, T 3S, R. 31E., M.D. (high pozzuolanic)	75.87	11.23	1.45	1.59	0.05	comb.	—2.28	2.94	4.96
Wind-laid pumicite, north of Laws, secs. 27-28, T. 3 S., R. 32 E., M.D. (high pozzuolanic)	77.26	9.94	1.82	1.71	0.08	comb.	—2.59	3.15	3.91
Water-laid lump pumice, Coso dist., Owens Valley, Calif. (typical analysis of mixed pumice, several deposits)	63.41	18.80	2.68	3.62	1.48	comb.	—5.48	0.67	4.53
Water-laid tuff deposit, El Paso Range, Kern County, Calif.	67.50	14.40	0.96	1.24	0.64	0.77	5.41	-------	9.00
Wind-laid lump pumice, El Paso Range, Kern County, Calif.	63.90	23.86	1.20	0.39	0.40	3.88	3.08	------	3.83
Water-laid (?) pumicitic tuff, El Paso Range, Kern County, Calif.	66.52	23.34	0.80	1.20	0.34	3.38	1.12	------	3.22
Pumice, south of Glass Mountain, Modoc County, Calif.	72.75	13.83	0.78 FeO-1.61	1.80	0.62	3.80	4.00	tr.	------
Pumice at Glass Mountain, Modoc County, Calif.	73.10	14.10	0.57 FeO-1.86	1.50	0.35	3.80	4.10	tr.	------

Miscellaneous Uses of Pumice and Expanded Perlite

Pumice and expanded perlite have been used in the chemical industry as filter aids, as absorbent materials, and as catalyst carriers. Perlite (low bulk density pulverized) is being used experimentally as a filler in paints and enamels, and in the paper industry as a filler. Pumicite is in use as a carrier for insecticides where a low pH is required, as in the case of a carrier for DDT dust. As extenders in the rubber industry; as fillers and mordants in the textile industry; as ingredients in certain types of glazes in the ceramic industry; and as fillers in the plastic industry, certain types of pumice and pumicite (and the low bulk density expanded perlites) should find wide use. As soil modifiers and chicken litter, both pumice and perlite are used.

OCCURRENCE OF PUMICE AND PERLITE IN CALIFORNIA

It is beyond the scope of this paper to detail the known deposits of pumice and obsidian (including perlite) or to describe the geology of their occurrence. The geographical relationship of the areas containing the principal known deposits to areas of large population and consuming power is, however, of pertinent interest.

The principal districts where large deposits of pumice, pumicite and the obsidians (including perlite) are known to occur, together with some data on freight rates to principal consuming centers and value of the material at the deposits follow.

Northern Area. The northern counties of the State, notably Siskiyou and Modoc, have extensive deposits of pumice and perlite (and other varieties of obsidian). The principal shipping points for this area are Tionesta on the Southern Pacific and Alturas on the Western Pacific system. The principal markets at present for pumice and perlite produced in this area are the Sacramento-Stockton area of the northern San Joaquin Valley and the San Francisco Bay region. Freight rates (1946) were approximately as follows: on pumice, Tionesta to San Francisco Bay area, $4.00 per ton, or $2.00 per yard (weight allowance of

1,000 pounds per yard). Selling price of run-of-quarry pumice, f.o.b. car, was $3.00 per yard; of ground and screened graded concrete block aggregate, $3.75 per yard. Freight rates on crude perlite or obsidian rock were quoted at $3.75 per ton, but no schedule was set up as no volume was shipped. From Alturas, approximately the same freight schedules held, and crude perlite could be purchased for $6.00 to $7.00 per ton f.o.b. car.

Central Area. Immediately to the north of the San Francisco Bay region, notably in Lake, Napa, and Sonoma Counties, are deposits of pumice and of obsidian. No production of obsidian is reported, and the pumice mined is made into concrete blocks or other shapes in plants close to the pumice pits. Haulage is by truck, and production is used almost entirely by owners or lessees of the deposits in their concrete block plants. Markets are in the San Francisco Bay region. Fairly large deposits of pumice and pumicite of good quality are found in Fresno and Madera Counties in the vicinity of Friant. These deposits are in the same category as the deposits in Napa and Sonoma Counties, that is, production is used locally for the manufacture of prefabricated masonry units for local markets. Pumicite is mined in this district for use as an insecticide carrier, and is shipped by truck to the San Francisco area chemical plants. This material is sold for from $10 to $15 per ton, f.o.b. Friant. Pumice for prefabricated masonry unit aggregate can be bought in the San Francisco Bay region for from $6 to $7 per yard depending on grading and quantity.

Southern Area. The extensive deposits of high quality pumice and obsidian in the Mono Lake region and in the Owens Valley in Mono and Inyo Counties are geographically in the eastern central part of the state, but with the exception of the relatively inaccessible Mono Lake region, are tributary to the southern or Los Angeles area because of topography and transportation. In addition, extensive deposits of all varieties of obsidian and some deposits of pumice and pumicite are found in the Mojave Desert region of Kern, San Bernardino, Riverside, Imperial, and San Diego Counties and are tributary to the Los Angeles-San Diego areas of large population. Graded aggregate pumice f.o.b. car in the Owens Valley sells for $2.00 per yard ($4 per ton). Freight varies from $2.40 to $3.50 per ton ($1.20 to $1.75 per yard) to Los Angeles depending on whether shipping point is Lone Pine or points farther south in Owens Valley. Most shipments are made by truck (at about $2.50 to $3.00 per yard) rather than by railroad. Owens Valley is served by the Southern Pacific. In addition to aggregate pumice produced by several firms and individuals, the Pacific Coast Pumice Company of Bishop, California, produces all the standard grades of acoustic and abrasive pumice, most of which is shipped to midwestern and eastern states by rail. Aggregate pumice is hauled from the deposits to crushing and screening plants located on the highway or railroad, by truck, at a cost of approximately 3 cents to 6 cents per yard mile (about 1.5 cents to 3 cents per ton-mile). Prevailing selling price for graded pumice aggregate in the Los Angeles area is from $3.50 to $5.00 per yard in quantity purchases. Small lots are higher in price, and local haulage charges are added.

Many large deposits of perlite and other varieties of obsidian are reasonably close to the Santa Fe railway between Barstow and Needles. Freight on crude perlite rock into the Los Angeles area from points

close to these deposits ranges from $3.90 per ton to $2.50 per ton depending on the distance and tonnage moved. Corresponding rates into the San Diego area would be 50 cents to 65 cents per ton more. Good grade crude perlite rock can be purchased in tonnage f.o.b. car at Aguila, Arizona (freight to Los Angeles $3.91 per ton), for $5.00 per ton.

Most firms planning to produce expanded perlite own or lease deposits of perlite rock. Under prevailing lease terms, a royalty is paid to the owner. This ranges from 10 to 50 cents per ton depending on hauling distances, cost of quarrying, and other factors. It must be emphasized that perlite rock is a cheap and abundant material, and that the largest and most accessible deposits of uniformly good quality closest to large centers of consumption will be exploited in the order of their quality and accessibility.

ADVANTAGES OF EXPANDED PERLITE OVER PUMICE

As previously explained, expanded perlite is a synthetic pumice. One may then ask why such a synthetic material, produced by somewhat complicated and relatively costly processing operations, can successfully compete with pumice in any of its uses in the west, as pumice deposits of good quality are widely distributed in most of the western states. The present and ultimate advantages of expanded perlite over pumice may be summarized as follows:

(1) Greater potential supplies of obsidian capable of expansion exist than is the case with pumice, and the deposits are as a rule larger and more concentrated.

(2) Perlite may be shipped from the mine or quarry in the form of crude, heavy rock in gondola cars at low freight rates compared to pumice, which must be shipped approximately the same distance to consuming centers in the form of a light, bulky, friable material.

(3) Crude perlite rock shipped into the centers of consuming areas may there be expanded into a variety of products in processing plants of relatively small unit capacity and cost. By multiplication of such units local and variable demand can be met.

(4) Pumice varies in its physical properties (bulk density, porosity, crushing strength, degree of alteration, etc.) because its expansion and deposition are the result of haphazard natural processes. Perlite, if quarried with some attention to uniformity, may be expanded under definite and controllable conditions to produce synthetic pumice of uniform specifications within a much wider range of physical properties than natural pumice.

Assuming that the obvious advantages of inert lightweight mineral fillers and aggregates will lead to a large continued demand for these products in the future, and that the technical difficulties involved in the commercial processing of perlite on a large scale will be solved, it is probable that expanded perlite will eventually supplant pumice in most of its uses except where pumice deposits of good grade are close to consuming centers.

PROCESSING OF PERLITE

The fact that certain types of obsidian, notably the perlitic variety, will expand up to 20 times volumetrically upon sudden exposure to heat within a range of about 1400° to 2500° fahrenheit, followed by sudden cooling, was probably first utilized commercially in Germany. There,

prior to 1925, obsidian was preheated to approximately 900° centigrade and then dropped through a shaft furnace against a rising current of hot gases. The resulting expanded obsidian was formed into shapes, with lime as a binder, for use as abrasive bricks. However, it appears that no attempts to commercialize upon the possibilities were made in the United States until about 1940. Since that time many individuals and firms have undertaken research upon methods of processing perlite and uses for the material. To date, several million dollars have been spent in this research. Much of it unfortunately has been poorly planned research, or plant construction based upon inadequate fundamental technical knowledge.

Expanded perlite is a glass foam consisting of masses of small, essentially spherical bubbles surrounded by thin walls of high-silica glass. The raw material is an obsidian containing evenly distributed dissolved or chemically combined water, and possibly gases. This material is crushed, usually screen sized, and heated in a suitable furnace at a suitable rate of heating to that critical temperature at which the gas-forming constituents, acting against the pasty heat-softened glass, will form bubbles within the mass of the glass particles. This causes the mass to expand. At this point the material is ejected from the furnace and cooled rapidly before the expanding gas bubbles have had time to escape from the mass of the glass. There are several variables involved in this process.

Variation in Raw Material. Perlite is a rock, not a mineral, and therefore is variable in chemical composition within a wide range. Composition of separate deposits differ, and there is variation even within the same deposit (see table 2). These variations in chemical composition strongly affect the softening point or viscosity at a given temperature, the type and degree of expansion, the size of the bubbles, the wall thickness between bubbles, and the porosity of the resulting product, as well as other physical properties of the expanded material. To date, very little fundamental research has been concluded upon these and other important variables affecting the control of the processing of perlite. The most that can be said at this time is that, in general, a perlite rock containing more than 74 percent silica, more than 12 percent alumina, less than 5 percent combined alkalis (sodium and potassium oxides), and less than 2 percent total water, will usually require over 2000° fahrenheit expansion temperature and a relatively long time (on the order of many seconds rather than fractions of a second) in the hot zone, and will tend to yield a relatively heavy but structurally strong and minutely vesicular product. Likewise, a perlite in the range of 70 percent silica, less than 14 percent alumina, more than 8 percent combined alkalis, with appreciable calcium, iron, and manganese oxides (3 or 4 percent combined), and with more than 3 percent total water, will usually expand in a temperature range between 1300° and 1700° fahrenheit. It will also tend to yield a relatively lightweight coarsely vesicular and friable product, and will require a relatively short time contact at maximum temperature (a fraction of a second to a second or two).

The foregoing rough variations in silica, alumina, alkali, and water content represent the practical range in analyses of expanding obsidians. Higher silica plus alumina and lower alkali content obsidians are too viscous at practical furnace temperatures to expand properly. More

basic glasses (silica content much lower than 70 percent, and higher alkali, lime, magnesia, and iron content than the above range) are too fluid near the softening point to retain the bubbles of expanding gas, and result in a product too coarsely vesicular.

One of the most important variables in raw perlite is the amount and type of contained water or gas. The force which causes a cellular structure in expanded perlite is expansion of contained water vapor or other gas. The effect of contained water upon viscosity at elevated temperatures is marked. Some expanding obsidians contain less than 0.2 percent total ignition loss (including water) but will expand satisfactorily at furnace temperatures above 2200° fahrenheit. The expanding agent in some of these cases may be gases other than water vapor, but not necessarily so. Even 0.1 percent of combined water is theoretically ample to give several hundred percent volumetric expansion at about 2000° fahrenheit. Little is known about the physical or chemical state of the water in obsidians. Some of it is undoubtedly loosely bound or in simple solution. Some of it is tightly bound in chemical combination, and probably some of it is not in the rock in the form of water at all, but in the form of an acid radical. Until careful thermal analyses of obsidians are made, no real understanding of these problems is possible.

Practically, the foregoing considerations are recognized in the processing of some perlites. An example would be the case of a high-alkali, high-water content perlite from which it is desired to make a very finely vesicular, fairly heavy and strong product suitable for concrete aggregate. This is done by slowly preheating the crushed and sized material for a relatively long time, thus driving off the loosely bound water by diffusion. The material is then passed into a hot zone maintained at a temperature suitable for expansion. A relatively slow, even, and almost three-dimensional expansion then takes place. If the raw material is subjected to an expanding heat before some of the water is driven off, it is difficult to produce anything but a very light, structurally weak, and coarsely vesicular product.

Theoretically, the perfect expansion furnace for processing perlite should be sufficiently flexible in control of heat bands and time factor to handle any perlite or obsidian suitable for expansion, and make from it a product conforming to specifications within a wide range of porosity, bulk density, and crushing strength, without variation in the product from day to day. Practically, it is doubtful if any one furnace will ever reach this degree of perfection, although some may approach it. Most obsidians and perlites, if they are at all subject to "popping," will expand rather easily in almost any kind of a furnace into rather definite end products characteristic of the particular raw material used. It is usually somewhat difficult to change the characteristics of these products by manipulation of furnace conditions. It would therefore seem sensible to give the inherent characteristics of the raw material due weight, as demonstrated in any particular furnace, by selecting perlite from a deposit that would tend to give the desired product with the least cost and trouble in the particular furnace used; or conversely, to adapt the furnace type to the type of perlite available.

Control of Physical Properties of Expanded Perlite. To date, there are no generally accepted standards and specifications by which the suitability of a given processed perlite for a specific use may be judged. For

use as a lightweight aggregate with any binder (cement, gypsum plaster, some plastics, etc.) requiring mechanical mixing and hand or mechanical application of the mix, the following rough specifications are suggested:

(a) Apparent specific gravity of the material should be less than 1. For practical purposes, over 90 percent of the expanded perlite should float on water.

(b) Bulk density is a rough measure of the crushing strength of expanded perlite. It may be obtained by slowly pouring the material into a box of one cubic foot volume until the box is overflowing, striking off the top level, and weighing the contents. The bulk density of the expanded perlite most suited to a given aggregate is the minimum at which mechanical breakdown of the aggregate in mixing and application is a minimum, and yield in cubic yards of applied mix is a maximum. This bulk density will vary from 3 or 4 pounds per cubic foot, with individual expanded perlites used as lightweight cast insulating slabs with lime, bentonite, or plastic binder; through 8 to 12 pounds per cubic foot for hardwall plaster aggregate; to 12 to 20 pounds per cubic foot for concrete aggregate. The crushing strengths of various expanded perlites of the same bulk density will vary widely according to the type of raw material and the method of processing, but no standard test suitable for comparing different expanded perlites of the same bulk density is available at present. The only method open to a user of expanded perlite aggregate is to make up standard testing shapes of the various types of expanded perlite in the bulk density range desired, with the same mix and binder, and test the resulting concrete or plaster for compressive strength and other properties desired. If other variables than the type of expanded perlite are kept constant, and the work is carefully done, a fairly accurate picture of the comparative usefulness of the various types of material under the specifications of the finished concrete or plaster mix tested, may be secured.

(c) Porosity of expanded perlite will range from a frosty appearing, highly porous material to an aggregate of glazed particles having almost no porosity. Hydroscopic properties may be measured by determining the weight of water absorbed by 1 cubic foot of the material after passing air, at 90 percent humidity and room temperature (70° fahrenheit), through the material for a week. For most uses this figure should be below 2 percent. The direct measure of water absorption by immersion tests is difficult and inaccurate, but a rough comparative working measure of water absorption (and adsorption) may be obtained by submerging a weighed quantity of the material (this requires either a fine mesh screen or metal plate to force the perlite under water) for 24 hours and then removing the expanded perlite and allowing it to drain freely for half an hour. Gain in weight may then be calculated and percent by weight or volume of water absorbed and adsorbed can be determined. For interior hardwall plaster aggregate, good results are attained with an expanded perlite of 30 to 40 percent (by weight) water absorption by the above method. For a concrete aggregate, a much lower water absorption is best (as low as possible). Good properties have been found in concretes made with expanded perlite aggregate giving from 10 to 20 percent water absorption by the above method.

(d) The ideal size grading of an expanded perlite aggregate or filler will depend on the specific mix and binder used, as well as the

properties sought in the finished wall or unit. In processing perlite, experience has demonstrated that sizing, where screens must be used, should be done on the raw material before expanding and not on the expanded product. With the ratio of expansion known, and the screen analysis of the desired expanded perlite known, it is relatively simple to approximate the screen analysis of raw feed necessary to produce the desired result in the expanded product. By a few empirical adjustments the size range desired in the finished product may be attained. Where air classification is used to size the finished product, close sizing of the raw material is not so important although if it is not done, undesirable by-product sizes are apt to be made. Great difference of opinion exists upon the subject of size grading when using lightweight mineral aggregates. In the case of expanded perlite used for interior plaster aggregate where light weight, excellent insulation properties, and good acoustic properties are more important than low porosity, a grading of approximately all through 8 mesh, with not more than 5 to 10 percent through 100 mesh (and the intermediate sizes bunched in the range from 30 to 60 mesh) has been used successfully. For exterior stucco and prefabricated masonry concrete, a grading of all through 4 mesh, 10 percent to 15 percent through 100 mesh, and intermediate sizes of approximately equal distribution has been used in concretes of adequate crushing strength and reasonably low water absorption (1,000 to 2,000 pounds per square inch in 28 days, 6 to 12 pounds water absorbed per cubic foot concrete, weight finished concrete air dried 40 to 70 pounds per cubic foot). There is some evidence that lower moisture absorption, higher crushing strength, greater age hardening, and greater resistance to corrosion in concrete are attained by the use of a rather large percentage of fines (—100 mesh) in mixes, or by the addition of 5 to 15 percent of pumicite or diatomite to the mix where the expanded perlite is deficient in the fine sizes. It is probable that small particle size expanded perlite will act as a pozzuolan as well as a filler ingredient in the mix, and thus not only add to the plasticity and workability of the mix, but result in a stronger and more impervious concrete.

PERLITE FURNACE TYPES

Many types of retorts or furnaces have been designed to "pop" perlite. Relatively few of these have been commercially successful. Most failures may be traced to faults in design resulting from failure to recognize and provide for factors outlined in the foregoing text. A good furnace should give good heat economy and be sufficiently flexible and exact in control of heat bands and the time factor to permit reasonable variations in analysis and physical properties of the feed without forcing a change in the specifications of the product. It should consistently produce, at the will of the operator, expanded perlite within a narrow range of bulk density, porosity, and size and shape of particle. It should be comparatively free from operating "bugs" such as building accretions, burning out tubes or liners, and mechanical breakdown. By variations in controls, the furnace should produce from the same raw feed, products within a bulk density of 3 to 15 pounds per cubic foot. It should also consistently produce whatever bulk density of product is desired within the aforementioned limits. To date, no operating furnace suitable for large-scale production is known that completely fills the above specifications, but several types in operation on a commercial or semi-commercial

Table 16. List of firms that had perlite expanding furnaces (laboratory to commercial sizes) in operation as of July 1947.

Alexite Engineering Co.
Alexander Film Co., Colorado Springs, Colo.

Chemi-Cote Perlite Co.,
435 S. Third Ave., Phoenix, Ariz.

Chemi-Cote Perlite Co. of Calif.,
6612 Sunset Blvd., Hollywood 46, Calif., (Sales Agency—HO 4804)

Continental Materials,
Las Vegas, Nev.

Continental Materials,
Bay Blvd. & J St., Chula Vista, Calif.

Dant & Russell, Inc., Perlite Division,
St. Helens, Ore.

Great Lakes Carbon Co., Permalite Sales Dept.,
756 S. Broadway, Los Angeles 14, Calif.

Grolite Co.,
5069 Anna St., San Diego, Calif.

High Gradė Products Co.,
232 W. First St., Reno, Nev.

National Perlite Co.,
Kennedy Rd. at S.P. RR, Campbell, Calif.

Nu-Lite Company,
150 S. Illinois Ave., Hynes, Calif.

Perlite Corp. of America,
Chula Vista, Calif.

Perlite Industries of Arizona,
2233 E. Henshaw Rd., Phoenix, Ariz.

Precast Slab & Tile Co.,
1367 S. Kingshighway, St. Louis, Mo.

Raymond De-Icer Corp.,
169 N. La Brea Ave., Los Angeles, Calif.

U. S. Industries, (Production Research Inc.),
1230 Lincoln Ave., Pasadena, Calif.

U. S. Perlite Co.,
609 S. Grand Ave., Los Angeles, Calif.

Volcalite Co.,
Puente, Calif., (Bassett Siding)

Western Chemical Co.,
320 E. Washington Blvd., Los Angeles, Calif.

Western Perlite Corp.,
15th St. & RR tracks, Phoenix, Ariz.

The Perlite Fabricating Industry,
800 Euclid Ave., Las Vegas, Nev.

basis roughly approach them. Further refinements will doubtless be made in each as experience indicates.

Horizontal or Inclined Stationary Furnace. In its simplest form, the stationary furnace is merely a cylindrical or rectangular tunnel lined with refractory brick, approximately 3 to 9 square feet in cross-sectional area and 12 to 20 feet long. The burner is at one end, so placed as to direct the flame longitudinally in the center of the tunnel. The crushed raw perlite is fed from the top of the tunnel close to the burner and the velocity of the gases holds most of the perlite in suspension as it passes through the furnace. Some cold air wash of the walls is secured by the venturi effect of the burner when the firing end is open. As accretions build on the furnace walls, they are knocked off with an air lance. Capacity is one-quarter to three-quarters of a ton per hour. The principal objections to this simple furnace are that constant attendance is required to regulate feed and knock off accretions, and little or no control of product can be secured by furnace regulation. Various modifications of the simple horizontal tunnel furnace have been designed to overcome the objections cited. The most successful of these modifications is a cylindrical retort approximately 2 feet in diameter by 15 feet long. It is open at both ends and provided with multiple bustle pipes approximately a foot apart along the length of the tube. These bustles are perforated to direct multiple air jets both parallel to and close to the walls of the furnace and at an angle therewith. Separate controls are provided for varying air pressure in each bustle. Feed is introduced at various points near the burner end, depending on the sizing of the feed (this is one method of regulating time of residence in the furnace). By regulation of the burner, the point of introduction of the feed, and the air pressure on the various bustle pipes, the time of residence of a particle in the furnace may be varied from approximately a tenth of a second to perhaps 3 or 4 seconds. Provision is made for close regulation of temperature.

The air jets prevent any of the perlite particles from contacting the walls of the furnace and all material is held in suspension within the rapidly moving stream of gases within the furnace. This type of furnace is extremely flexible and easily controlled in operation. Capacity is 1 to 4 tons per hour depending on the type of expanded perlite produced. The principal disadvantage is that a time of residence of a particle longer than some 4 or, at the most, 5 seconds cannot be attained at present. Fuel oil must be used rather than gas in order to attain the highest temperatures required and to obtain a long flame in the hot zone. Other types of horizontal stationary furnaces depend on the venturi effect of the hot gases to draw air through ports in the sides and thus give the furnace walls a cold air wash to prevent accretion. Some types provide for spray quenching and water flotation of the product at the discharge end of the furnace. Various other designs of inclined stationary furnaces have been tried.

Horizontal or Inclined Rotary Furnace. In its simplest form, the horizontal or inclined rotary furnace is a modified cement kiln with feed and burner at one end and discharge for ''popped'' material and hot gases at the other. In one variation the raw perlite is fed at one end and the furnace is fired at the other. This is the counter-current type; it was not successful, although the idea has some merit from the standpoint of subjecting the material to a high temperature after expansion has occurred, which tends to glaze the outside of the particles, reduce the porosity, and increase the compressive strength. Horizontal or inclined rotary furnaces now operating more or less successfully, are from 2 to 4 feet in inside diameter and from 8 to 25 feet long. All of them give some trouble because accretions build up on the walls, but in several types this trouble has been largely eliminated by the introduction of finely pulverized silica (such as diatomite) with the flame, thus coating the pasty perlite particles and preventing their sticking together or to the furnace walls. Control of temperature is by burner control. The time factor is controlled by varying the revolutions per minute, the angle of inclination of the furnace, or by varying the draught through the furnace, or all of these. Control is sufficiently flexible to permit continuous production of material within a reasonable range of physical properties.

At least two types of indirectly fired rotary tube furnaces are being operated semi-commercially. One type is essentially a series of stainless steel tubes in parallel enclosed in a firebox arranged so that the angle of inclination of the tubes may be changed. The tubes rotate and have individual drives and feeders. Multiple gas burners are placed beneath each tube. Control of rate of feed, variation of heat bands in each tube, time element within the furnace, etc., are very flexible and precise, and excellent types of expanded perlite within a range of 4 to 20 pounds per cubic foot can be produced with very little variation in properties over a period of time. Another type of indirectly fired tube furnace is essentially a number of cylindrical tubes mounted radially in a frame with the whole enclosed in a firebox arranged so that angle of inclination of the frame holding the tubes can be changed at will. The frame rotates about a central axis and the tubes are fed as they pass a central point. Control of temperature and time of residence within the furnace are secured by burner control and by varying the angle of inclination of the tube frame; also by varying the revolutions per minute of the frame. Excellent products are made in this furnace.

Vertical Type Furnace. In its simplest form, the vertical type furnace is a cylindrical or rectangular flue or chimney fired and fed at various points. Feed in most cases is at the top and firing at the bottom, although some types such as the Gilbert furnace (United States Patent #2,044,680) are both fed and fired from the top. Other types are fired and fed from the bottom. To date, more "bugs" have been encountered in the control and operation of vertical types of furnaces than in the horizontal types. Active research embracing all phases of perlite processing is still under way, and it is possible that one or more successful vertical type furnaces will evolve. A distinct type of vertical furnace, based on a modification of the familiar multiple-hearth roaster of the Wedge and Herreshof types common in all smelters has been experimentally used for the expansion of perlite. Results have been very encouraging. Very good heat economy, extreme flexibility of control of various heat bands on the several hearths, time of residence of the particles of perlite in each heat band, and the great variation in temperature possible between hearths, are advantages inherent in this type of furnace. By proper balance between preheating and expansion temperatures, almost perfect three-dimensional expansion is possible, resulting in a very finely vesicular, structurally strong but lightweight product of very low porosity in any size range from 3-inch down to minus 100 mesh. This material is highly suitable for concrete aggregate.

Other Heating Methods. Many other methods of expanding perlite have been tried or proposed, from heated inclined troughs to various electrically heated mechanisms. One interesting and perhaps practical method is the application of high-frequency induction heating to the expansion of obsidian (including perlite). This "diathermic" method literally heats the particles of rock from the inside out and produces perfect three-dimensional expansion in a product of very high strength-weight ratio.

COSTS AND SELLING PRICES FOR PROCESSED PERLITE

The present selling price in California for processed perlite ranges from 15 to more than 50 cents per cubic foot. There is no established price structure, and, to date, most purchases have been made for experimental or small-volume uses. The largest volume of sales has been as hardwall plaster aggregate in the San Francisco Bay region and as aggregate for precast masonry building units in the Los Angeles area.

Present prevailing price for expanded perlite plaster aggregate in the San Francisco area is about 35 cents per cubic foot. In the Los Angeles area this material has sold recently for 25 to 35 cents per cubic foot, and concrete aggregate for 15 to 40 cents per cubic foot.

Since no real volume of commercial production has as yet been attained by producers in any part of the west, competition to date has not been a factor in fixing price. In the near future, as volume production is attained and competition grows, the selling price may be expected to stabilize at some figure lower than present prices. Calculations based on data obtained from several producers and from other sources resulted in the estimated cost of production and probable future selling price range stated below.

The costs and prices appearing here are based on certain assumptions. They are based on a weight range of processed perlite averaging 15 pounds per cubic foot bulk density, suitable for the large volume

Table 17. Probable direct cost per ton of raw material.

	High	Low
Mining, crushing, and screening	$3.00	$1.50
Freight and handling to processing plant	5.00	1.00
All processing except bagging	6.00	5.00
Total direct cost per ton in bulk at plant	$14.00	$7.50

concrete and plaster aggregate markets. Operations must be efficient. Processing plants and quarries must be in states west of the Rocky Mountains. Shipments of crude or crushed and screened raw perlite must be made to plants located in large consuming areas in quantities of not less than 50 tons daily per plant. Quarrying of the perlite rock must be by open-pit methods with scale of operations at not less than 100 tons per day. Lastly, these costs and prices are based on the commodity price index of July 1947.

Probable Direct Cost Per Cubic Foot of Expanded Perlite. Converting the foregoing direct cost per ton of raw material, as shown in table 17, into cost per cubic foot of expanded perlite, at 133.3 cubic feet per ton, gives a cost range of 6 to 11 cents per cubic foot, in bulk, at the plant. Total bagging cost will vary between 4 and 8 cents per cubic foot if the material is sold in bags. Doubling the above direct cost figures to allow for fixed overhead and producers' profit will give a possible selling price between 12 and 22 cents per cubic foot, in bulk, at the plant, depending on local economic conditions and plant location. The price on bagged material might be between 16 and 35 cents per cubic foot, f.o.b. plant. Large users will probably be supplied in bulk, or, in the case of many fabricated products, the perlite used will be processed in or close to the fabricating plants.

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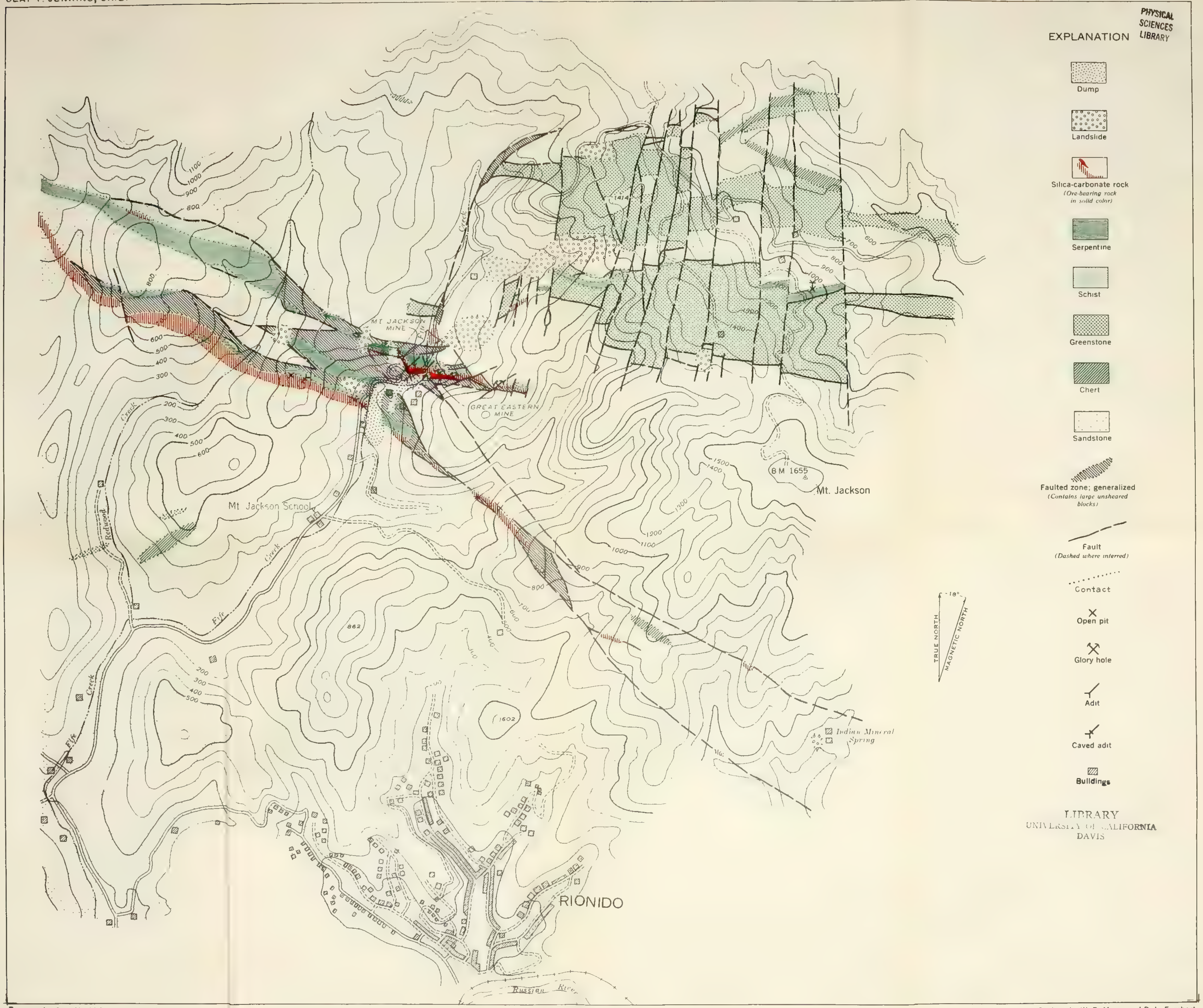


Topography from Healdsburg quadrangle
U. S. Geological Survey

Geology by W. B. Myers and D. L. Everhart

GEOLOGIC MAP OF THE GUERNEVILLE QUICKSILVER MINING DISTRICT

SONOMA COUNTY, CALIFORNIA

1000 0 1000 2000 3000 4000 FEET

Contour interval 100 feet

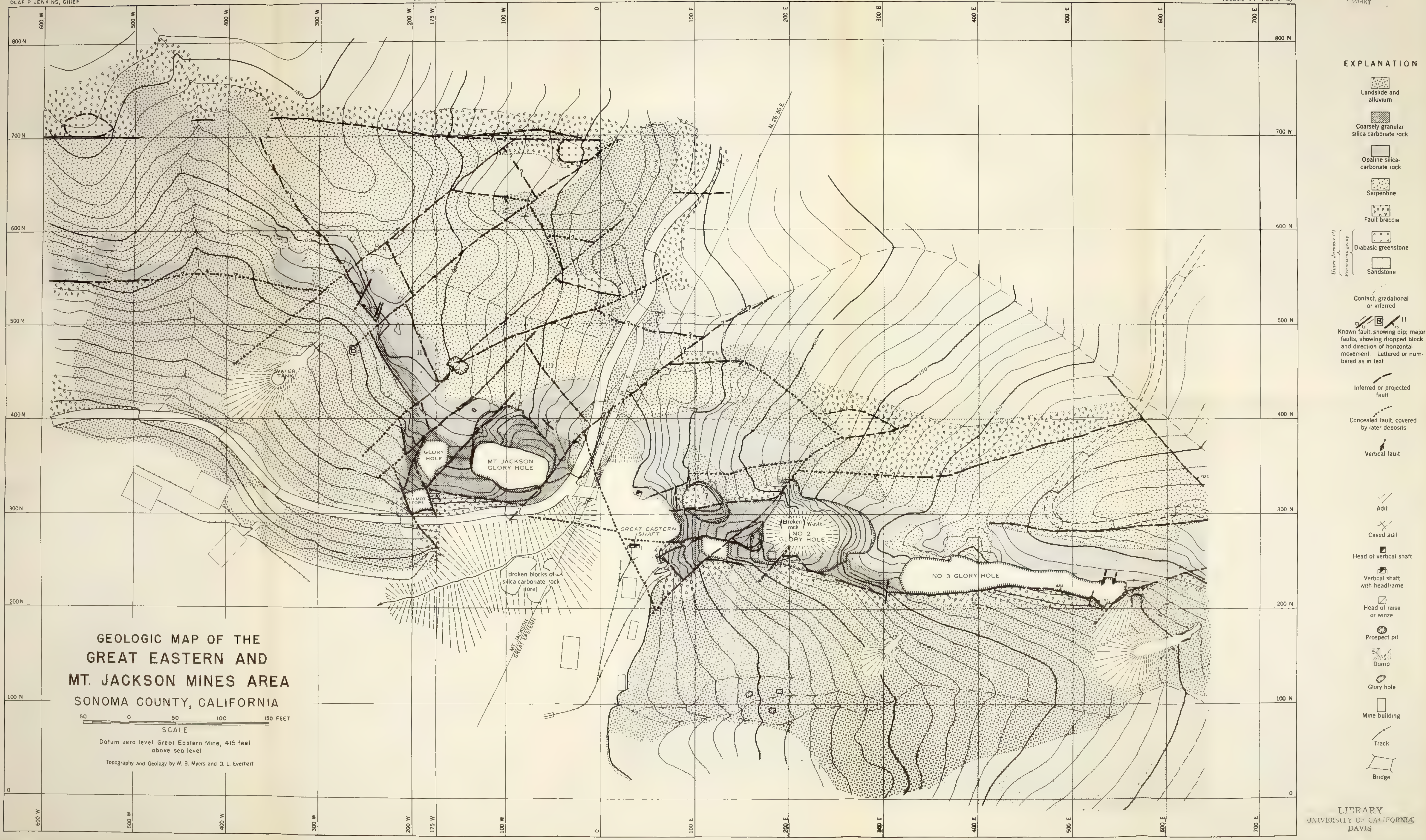
Datum is mean sea level

DIVISION OF MINES
OLAF P. JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

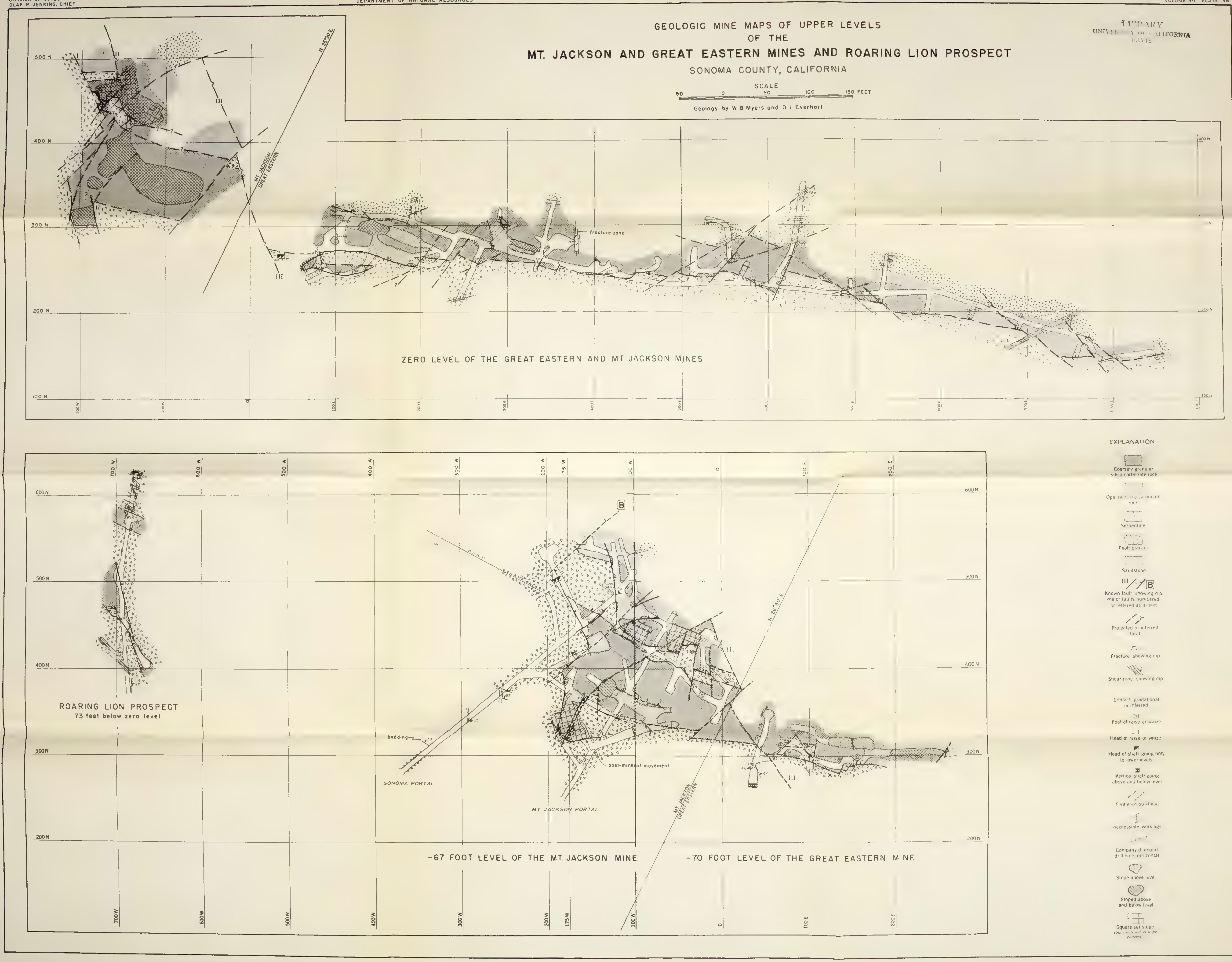
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

JOURNAL
VOLUME 44 PLATE 45



GEOLOGIC MINE MAPS OF UPPER LEVELS OF THE MT. JACKSON AND GREAT EASTERN MINES AND ROARING LION PROSPECT

SONOMA COUNTY, CALIFORNIA



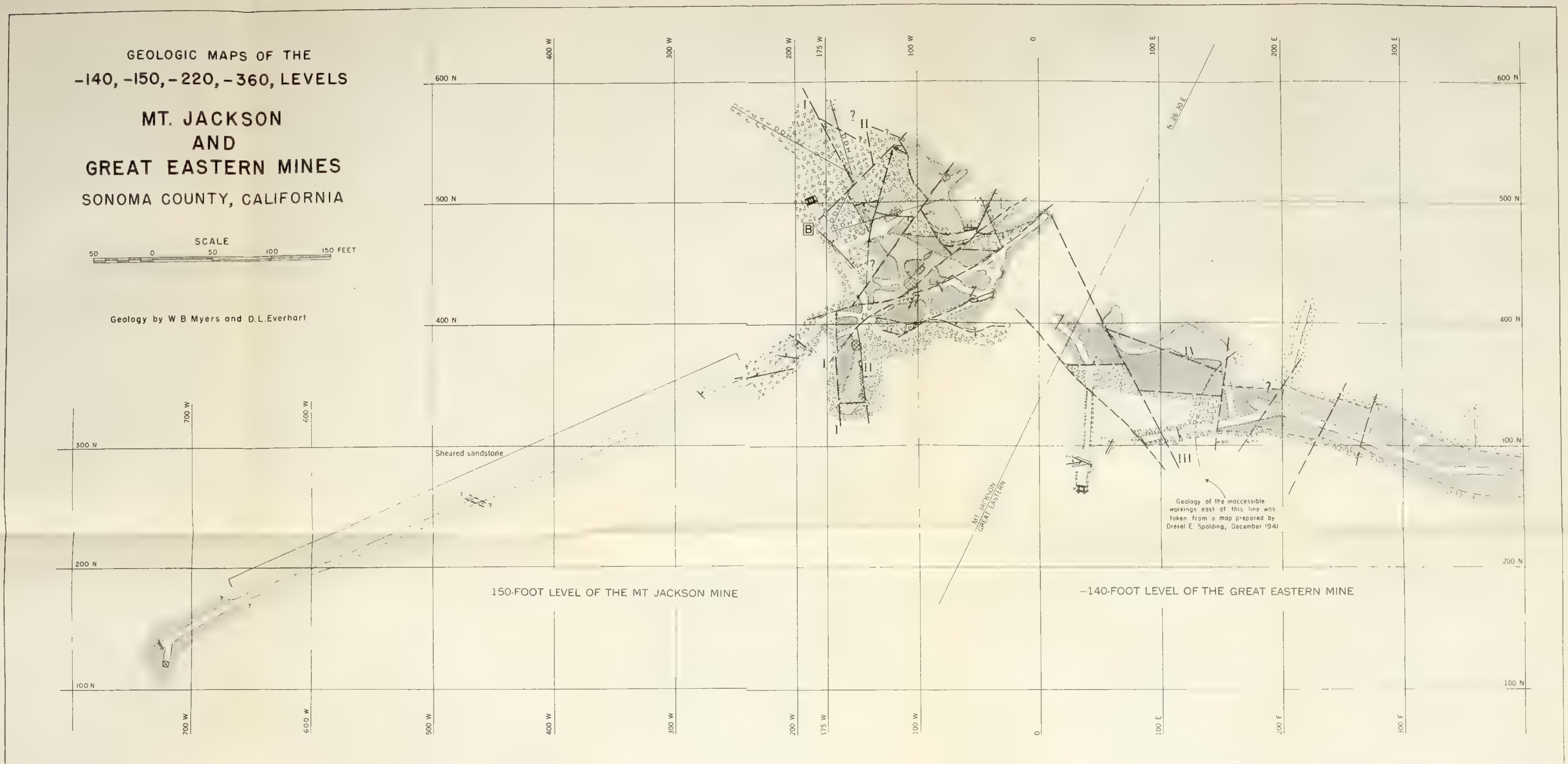
POCKET #2

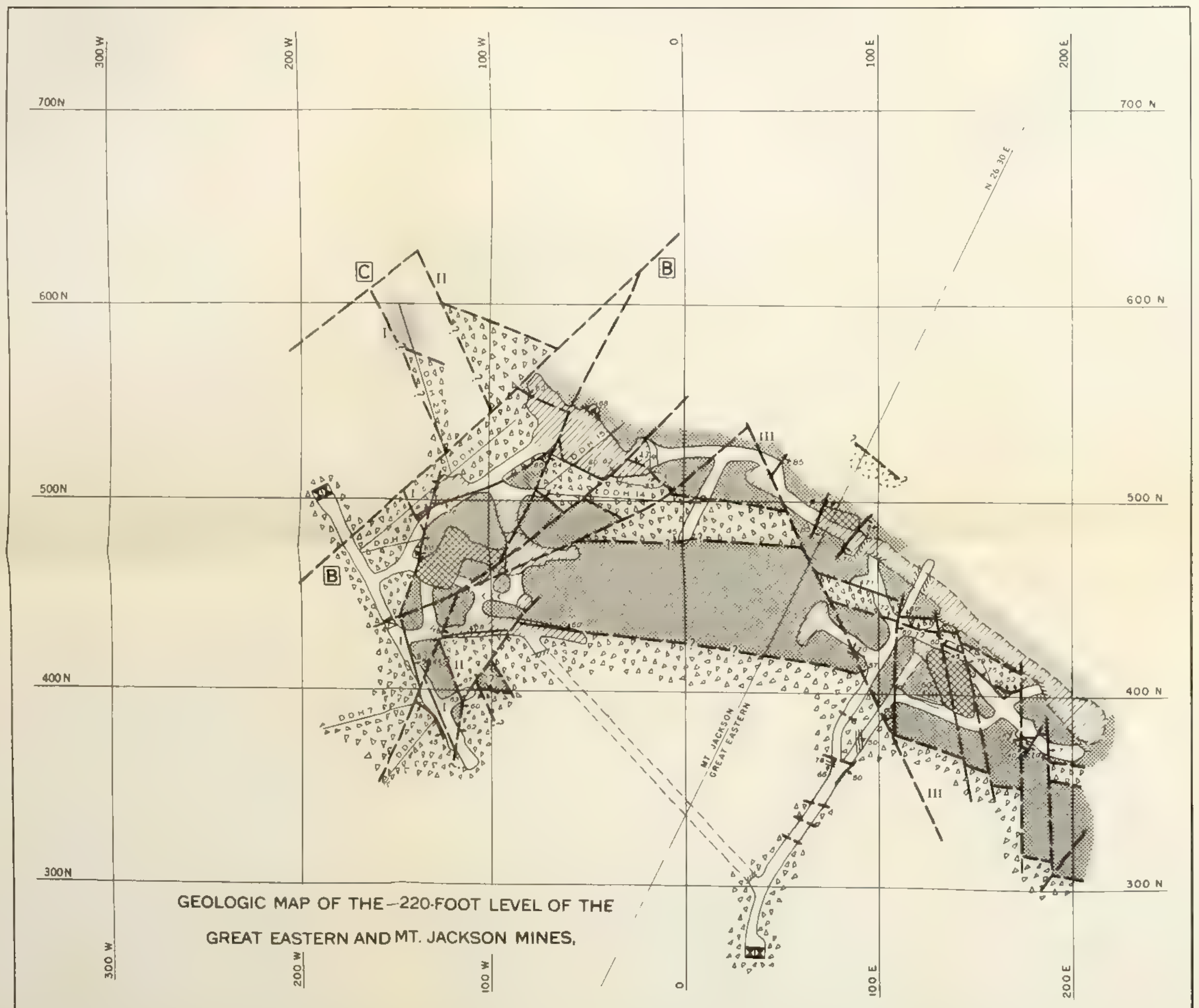
GEOLOGIC MAPS OF THE -140, -150, -220, -360, LEVELS

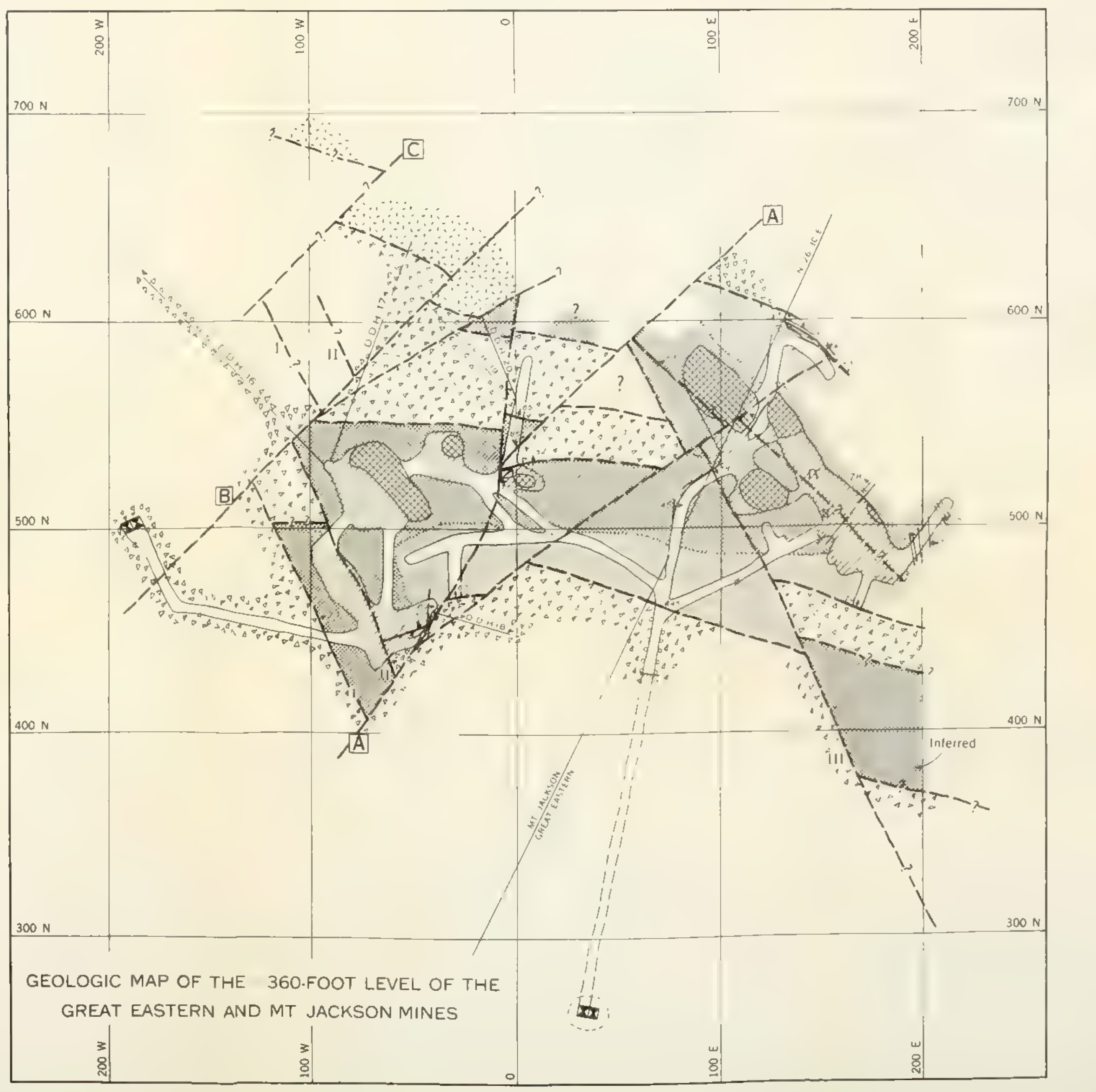
MT. JACKSON AND GREAT EASTERN MINES

SONOMA COUNTY, CALIFORNIA

Geology by W. B. Myers and D. L. Everhart





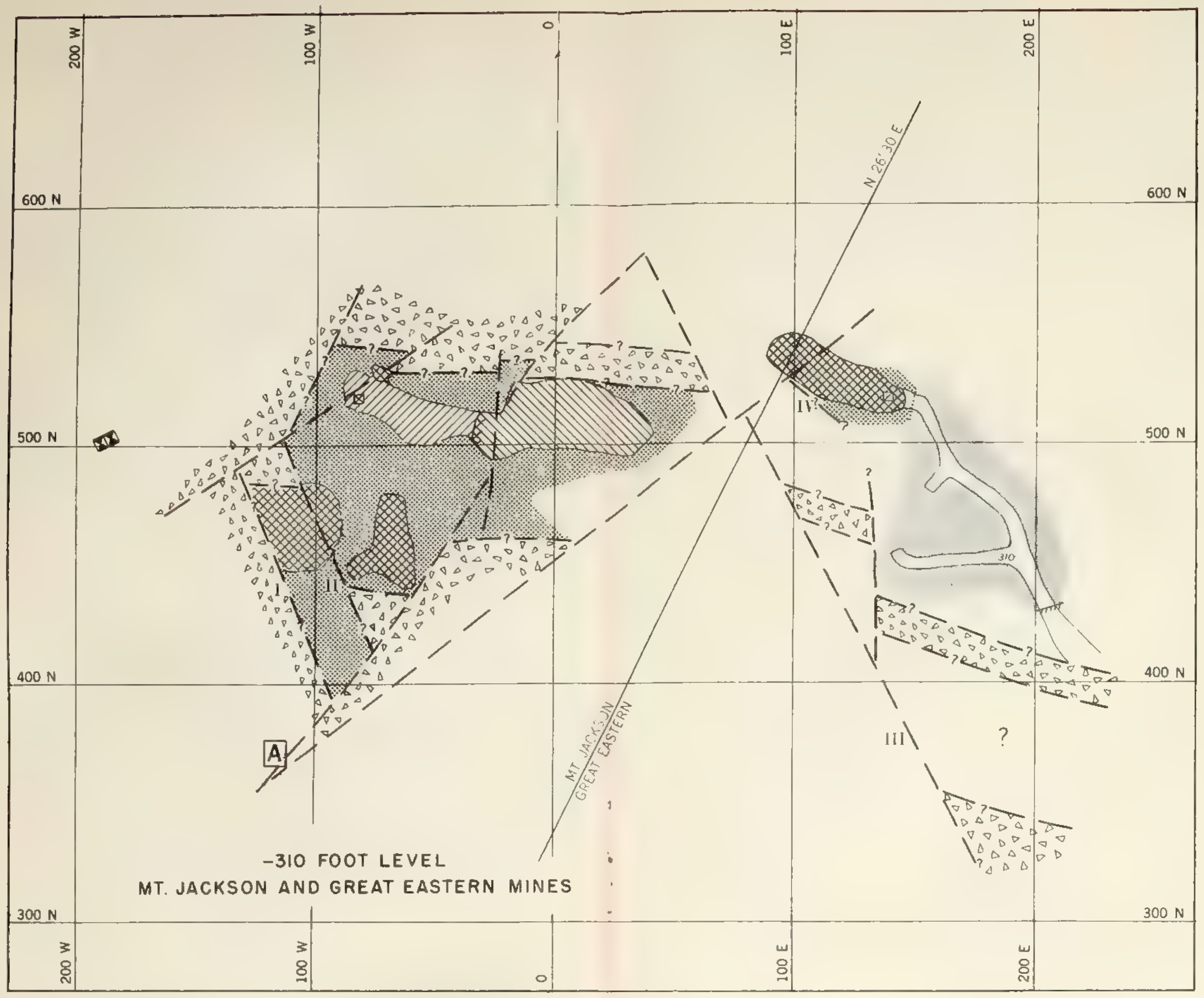


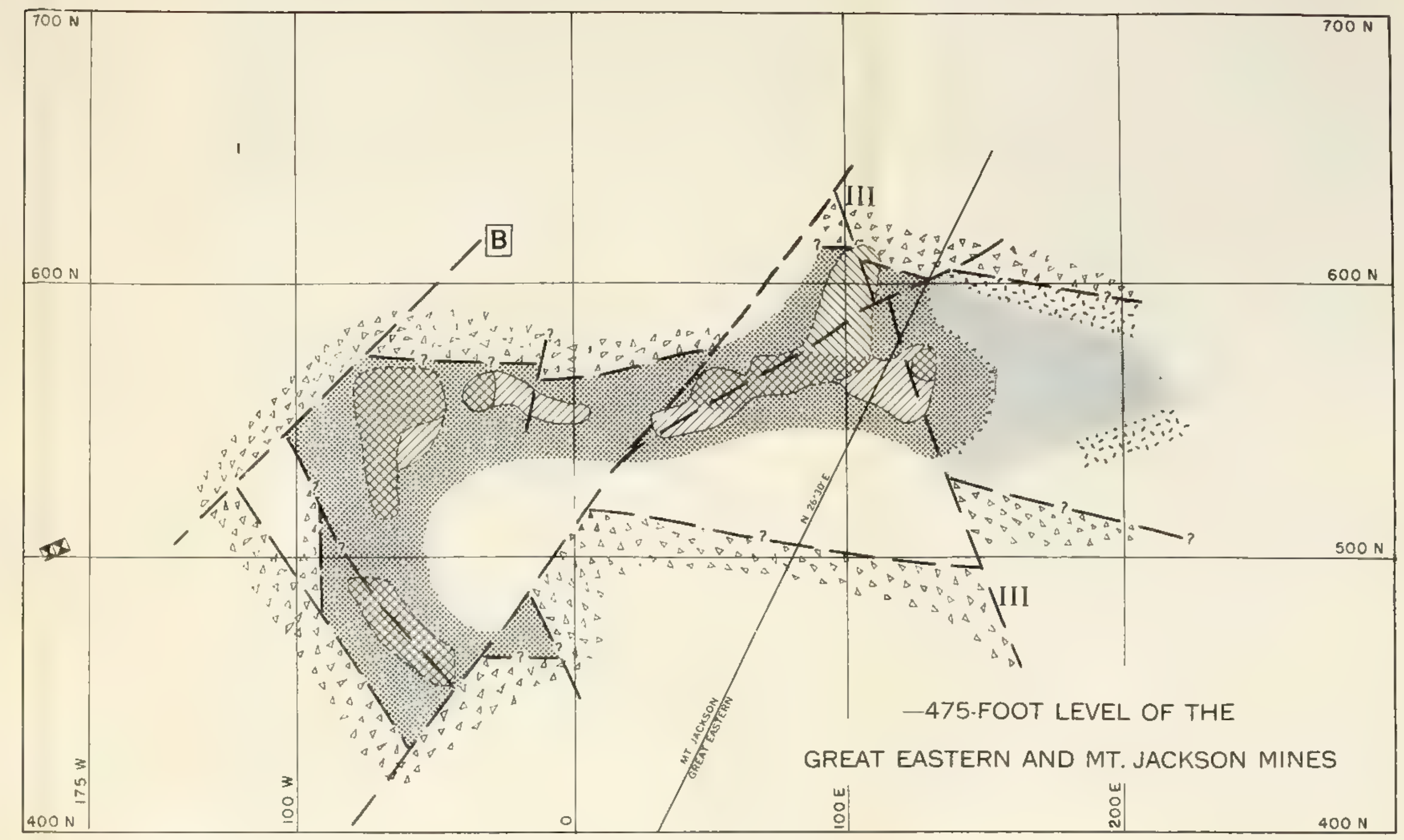
EXPLANATION

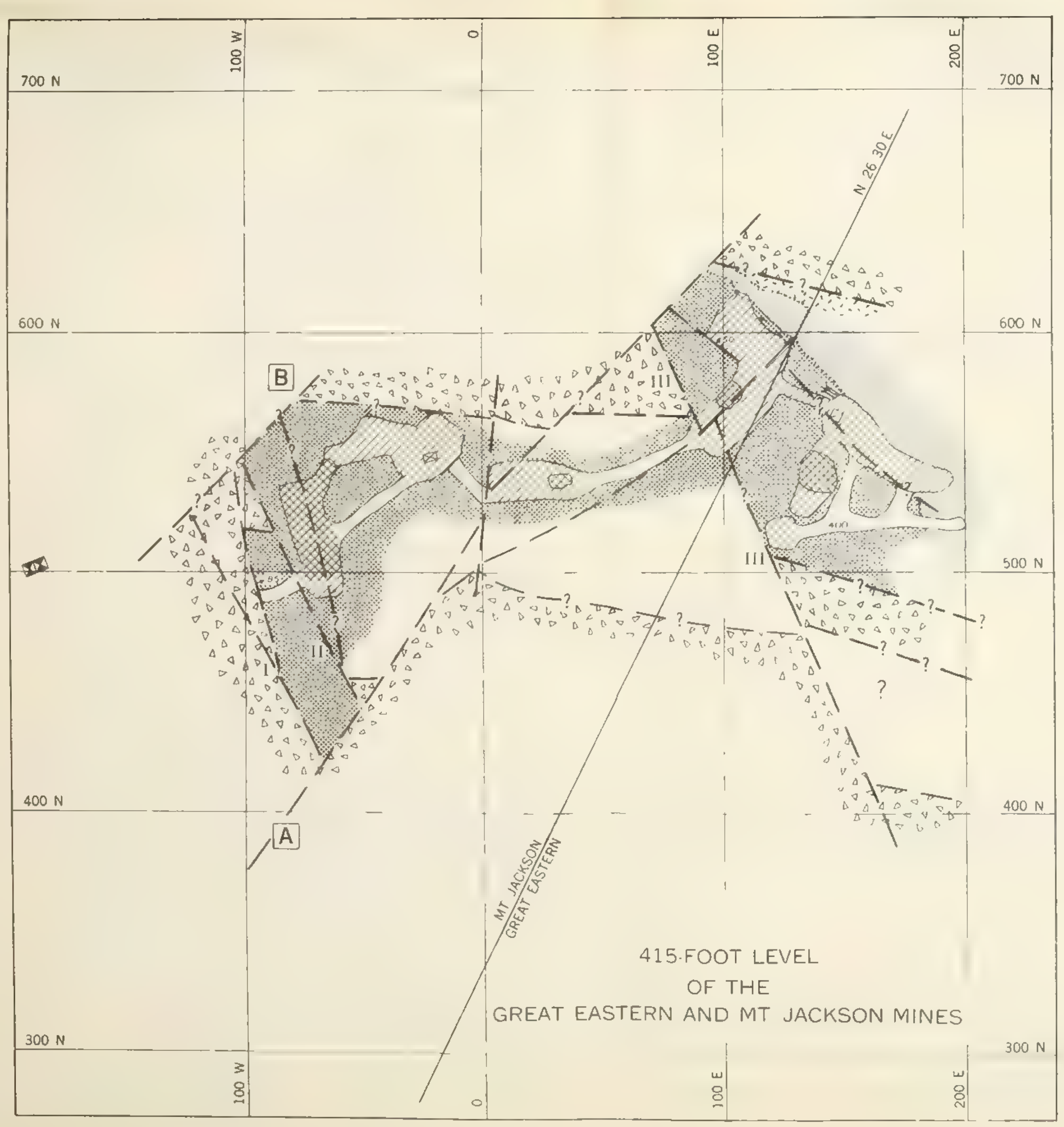
- Coarse, granular silica-carbonate rock
- Opaline silica-carbonate rock
- Serpentine
- Fault breccia
- Known fault, showing dip; major faults numbered or lettered as in text
- Inferred or projected fault
- Shear zone, showing dip
- Fracture showing dip
- Vertical fracture
- Contact, gradational or approximately located
- Foot of raise or winze
- Head of raise or winze
- Vertical shaft going above and below level
- Caved shaft
- Timbered bulkhead
- Inaccessible workings
- Company diamond drill hole, horizontal
- Stoped above level
- Stoped above and below level

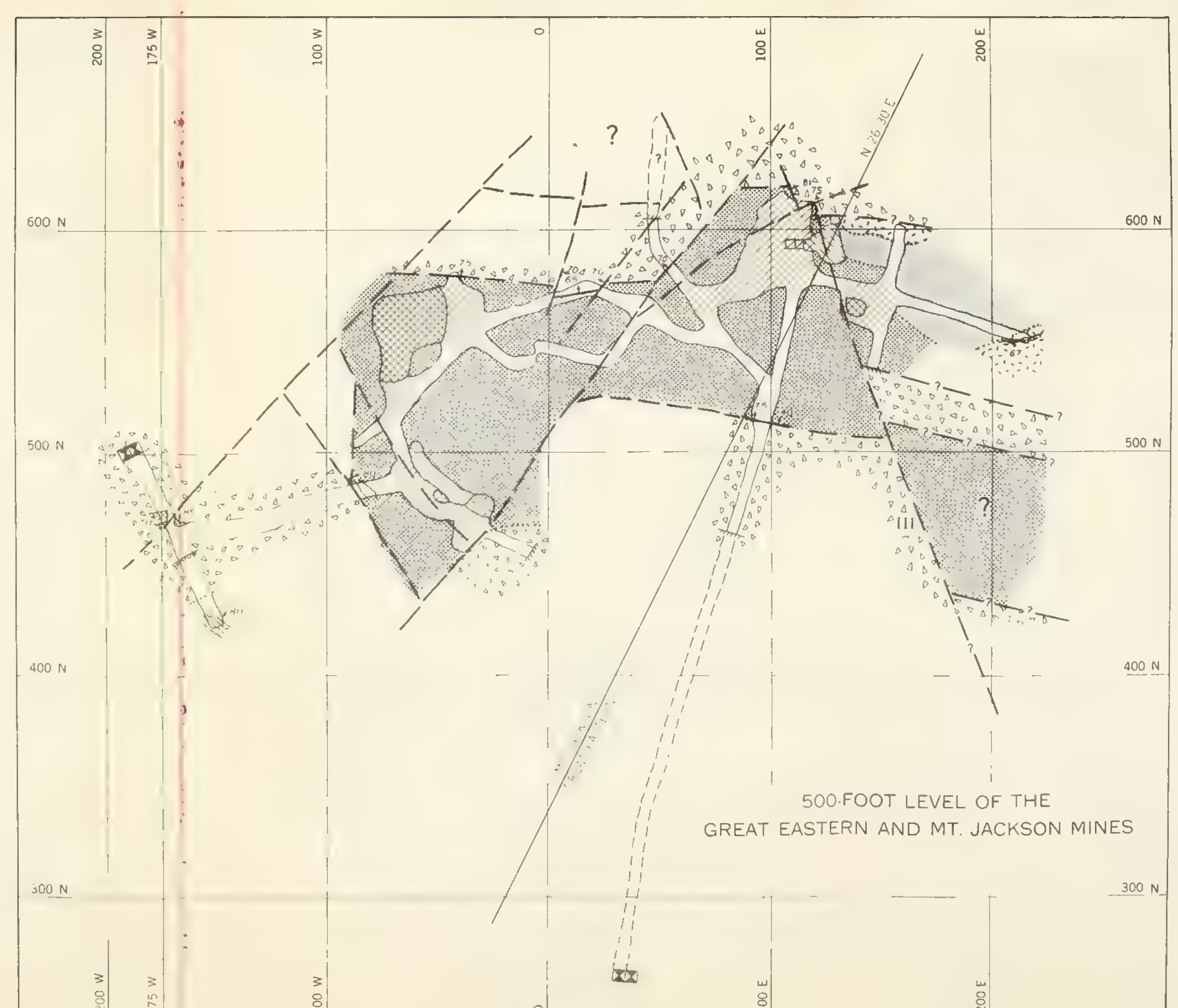
GEOLOGIC MAPS OF THE -310, -415, -475, AND -500 FOOT LEVELS MT. JACKSON AND GREAT EASTERN MINES SONOMA COUNTY, CALIFORNIA

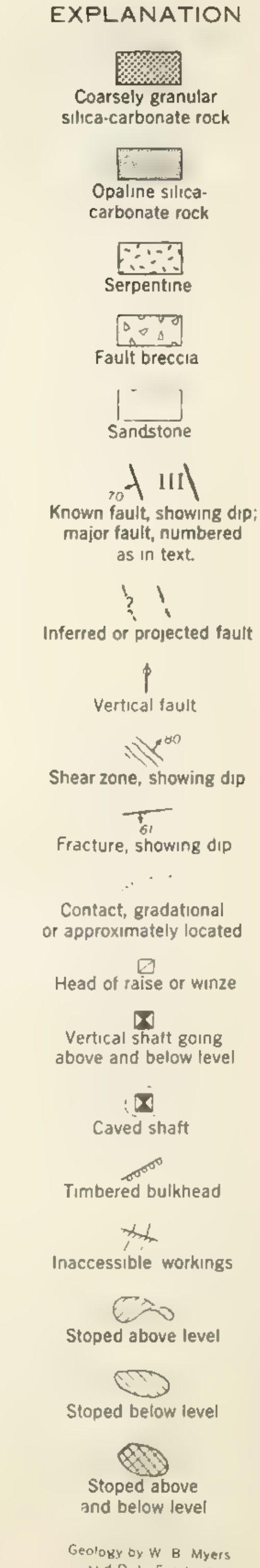
SCALE
50 0 50 150 FEET

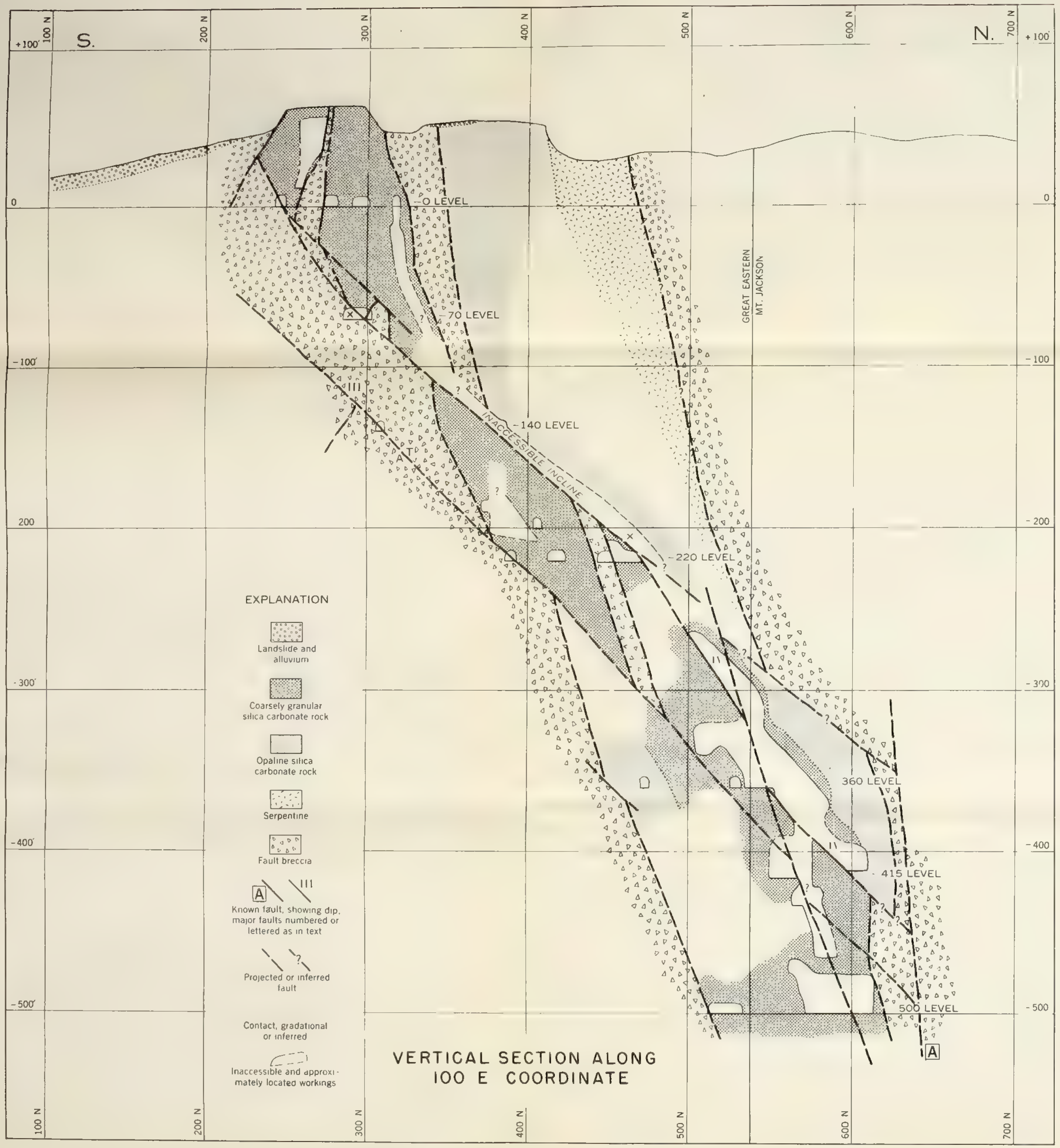


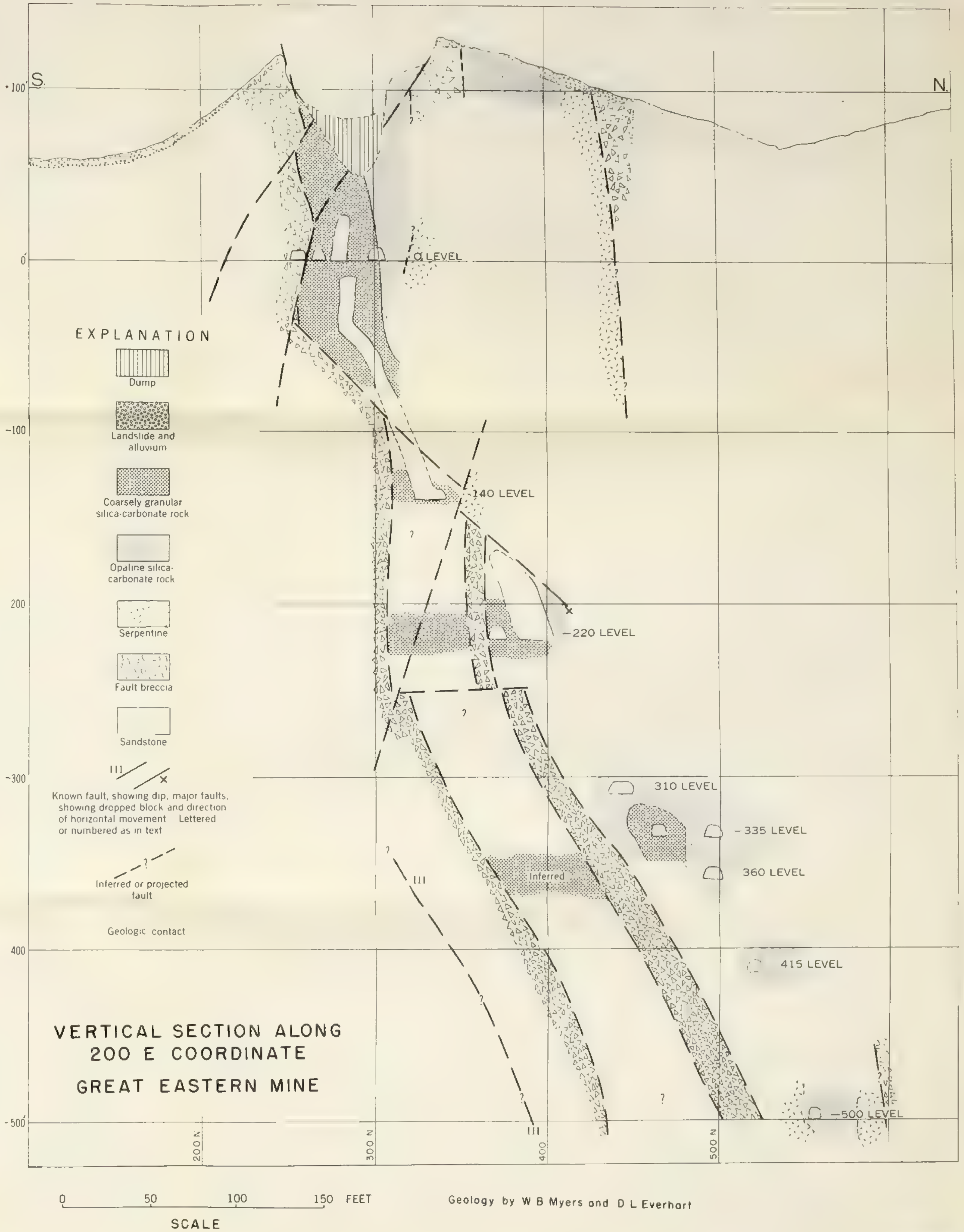












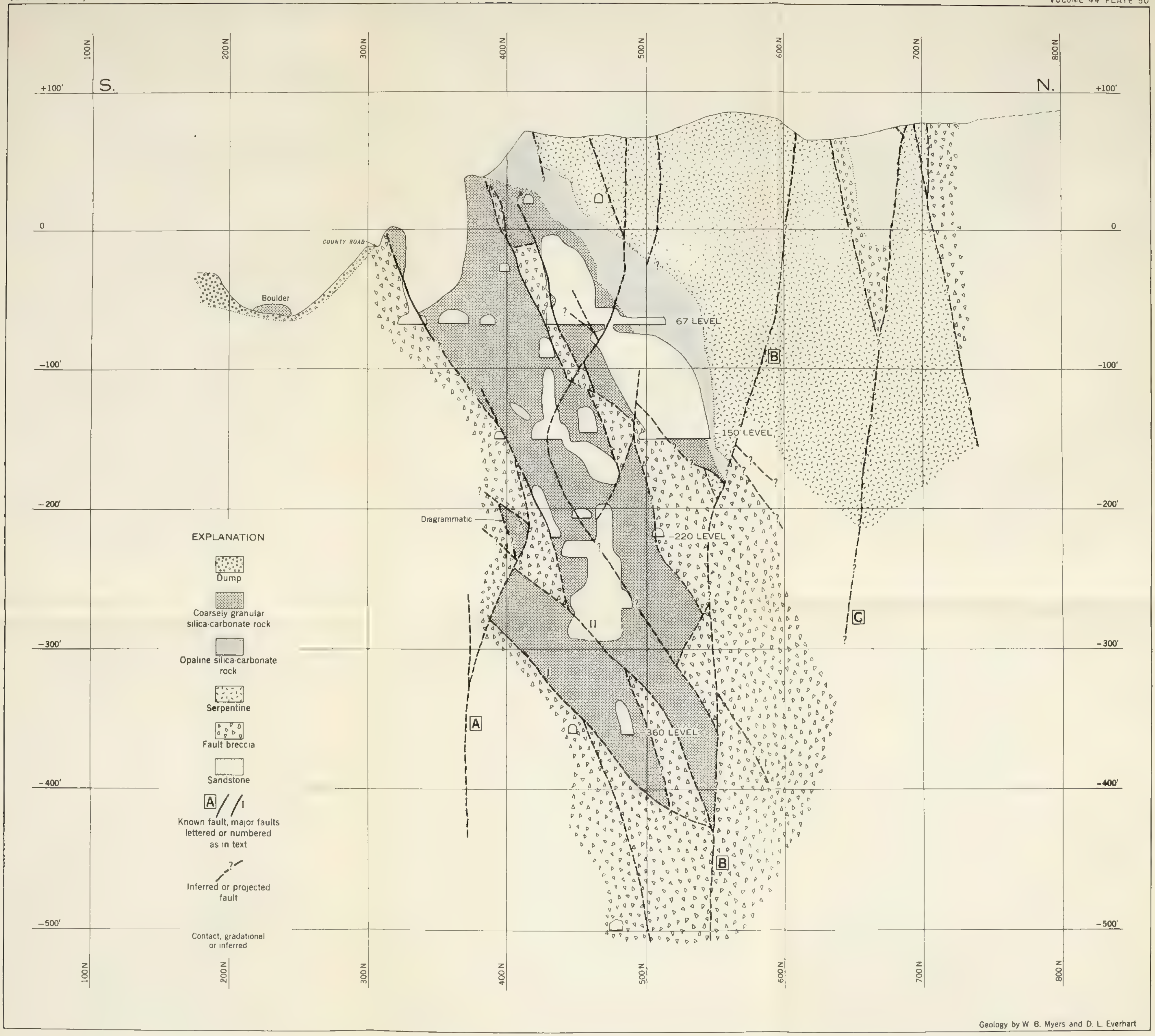
GEOLOGIC SECTIONS OF THE GREAT EASTERN AND MT. JACKSON MINES SONOMA COUNTY, CALIFORNIA

DIVISION OF MINES
OLAF P JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

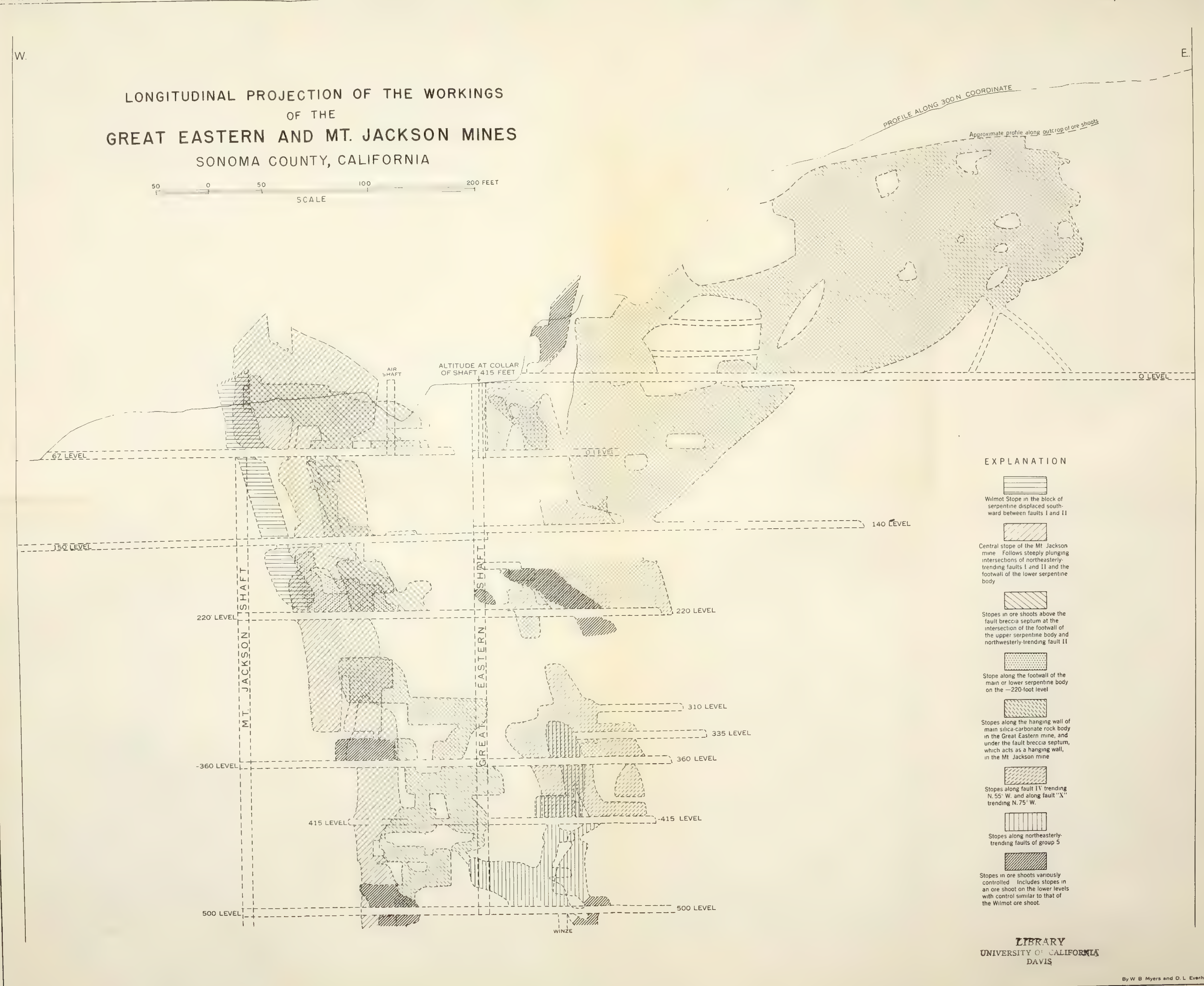
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

JOURNAL
VOLUME 44 PLATE 50



VERTICAL SECTION OF THE MT. JACKSON MINE, SONOMA CO., CALIF., ALONG THE 100 W COORDINATE

0 50 100 150 FEET


LONGITUDINAL PROJECTION OF THE WORKINGS
OF THE
GREAT EASTERN AND MT. JACKSON MINES
SONOMA COUNTY, CALIFORNIA
50
0
50
100
200 FEET
SCALE
W.
E.
PROFILE ALONG 300 N COORDINATE
Approximate profile along outcrop of ore shoots
AIR SHAFT
ALTITUDE AT COLLAR OF SHAFT 415 FEET
0 LEVEL
67 LEVEL
0 LEVEL
140 LEVEL
150 LEVEL
MT. JACKSON SHAFT
GREAT EASTERN SHAFT
220 LEVEL
220 LEVEL
310 LEVEL
335 LEVEL
-360 LEVEL
360 LEVEL
415 LEVEL
-415 LEVEL
500 LEVEL
500 LEVEL
WINZE
EXPLANATION
Wilmot Stope in the block of serpentine displaced southward between faults I and II
Central stope of the Mt. Jackson mine. Follows steeply plunging intersections of northeasterly-trending faults I and II and the footwall of the lower serpentine body
Stopes in ore shoots above the fault breccia septum at the intersection of the footwall of the upper serpentine body and northwesterly-trending fault II
Stope along the footwall of the main or lower serpentine body on the —220-foot level
Stopes along the hanging wall of main silica-carbonate rock body in the Great Eastern mine, and under the fault breccia septum, which acts as a hanging wall, in the Mt. Jackson mine
Stopes along fault IV trending N. 55° W. and along fault "X" trending N. 75° W.
Stopes along northeasterly-trending faults of group 5
Stopes in ore shoots variously controlled. Includes stopes in an ore shoot on the lower levels with control similar to that of the Wilmot ore shoot.
By W. B. Myers and O. L. Everhart

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

Vol. 44 | OCTOBER 1948 | No. 4

CALIFORNIA JOURNAL OF MINES AND GEOLOGY

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
OLAF P. JENKINS, Chief

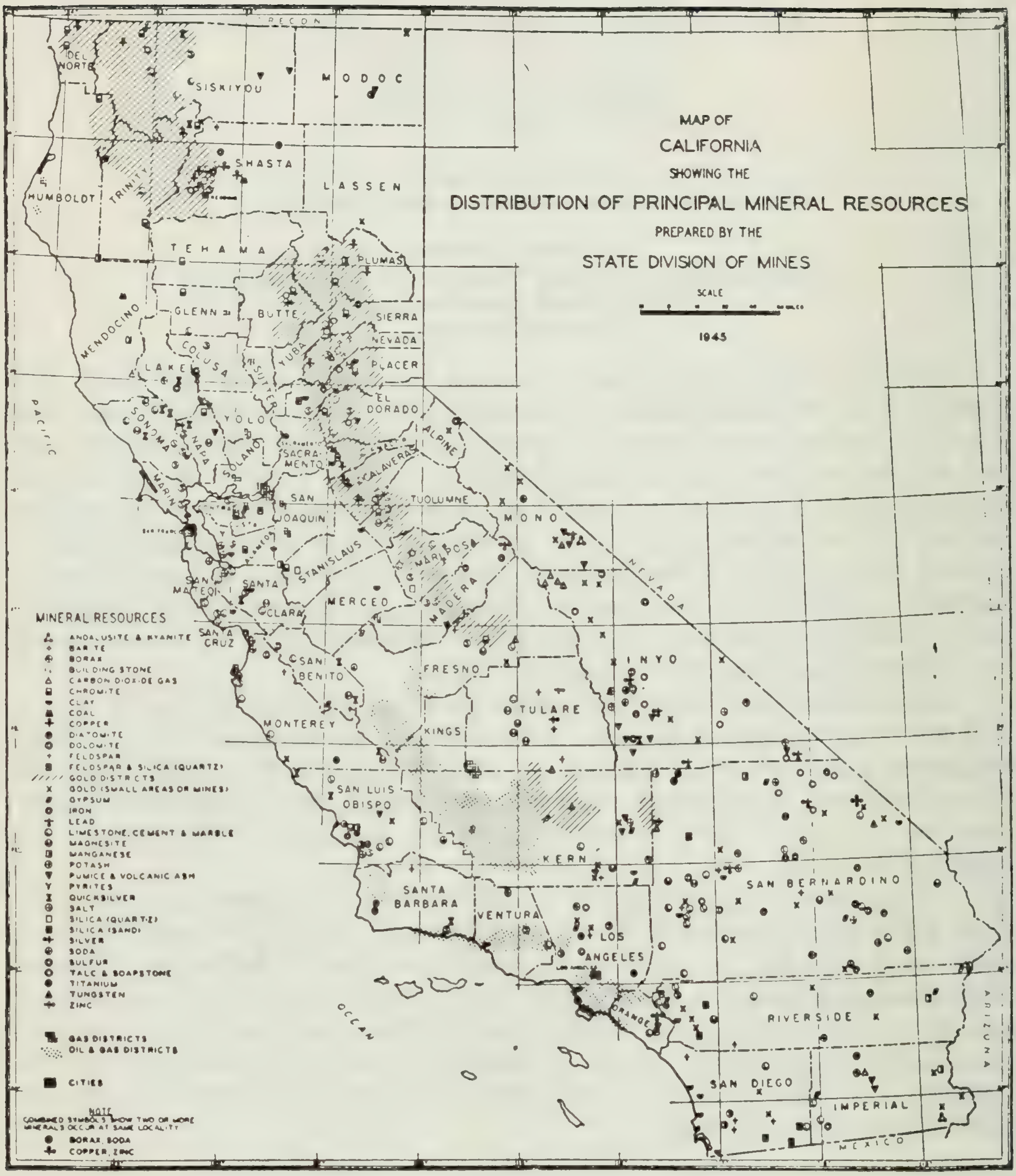
Headquarters
Third Floor, Ferry Building, San Francisco 11

District Offices
State Building, 217 West First Street, Los Angeles 12
631 J Street, Sacramento 14
Box 445, Redding

The Division of Mines maintains at its headquarters offices in San Francisco a technical library containing several thousand books and scientific journals on geology, mining, mineralogy, chemistry, metallurgy, and related subjects; a reading room containing periodicals devoted to the petroleum and mining industries, and newspapers from the mining centers of the state; exhibits of minerals, rocks, mine models, etc.; a service laboratory for the determination of California minerals; and a conference room with a mining engineer in attendance to serve the public and to sell publications of the Division. Publications are also sold at the Los Angeles and Sacramento district offices.

In addition to oral conferences in the offices of the Division of Mines, information concerning the mineral resources, mineral industry, geology, and mining operations of California is distributed to the public by means of publications, multigraph releases, and letters. Each letter of inquiry received by the Division is answered by the technical staff member best qualified to do so.

The principal publications of the Division of Mines are the quarterly **California Journal of Mines and Geology**, issued in January, April, July, and October of each year, and a series of **Bulletins**. **Mineral Information Service** is a monthly news release concerning the mineral resources and industry of California, designed to inform the public of discoveries, operations, markets, statistics, and new publications. It is distributed without cost upon request. A list of publications will also be sent free upon request.


MAP OF
CALIFORNIA
SHOWING THE
DISTRIBUTION OF PRINCIPAL MINERAL RESOURCES
PREPARED BY THE
STATE DIVISION OF MINES
SCALE
1945
MINERAL RESOURCES
ANDALUSITE & KYANITE
BARITE
BORAX
BUILDING STONE
CARBON DIOXIDE GAS
CHROMITE
CLAY
COAL
COPPER
DIATOMITE
DOLOMITE
FELDSPAR
FELDSPAR & SILICA (QUARTZ)
GOLD DISTRICTS
GOLD (SMALL AREAS OR MINES)
GYPSUM
IRON
LEAD
LIMESTONE, CEMENT & MARBLE
MAGNESITE
MANGANESE
POTASH
PUMICE & VOLCANIC ASH
PYRITES
QUICKSILVER
SALT
SILICA (QUARTZ)
SILICA (SAND)
SILVER
SODA
SULFUR
TALC & SOAPSTONE
TITANIUM
TUNGSTEN
ZINC
GAS DISTRICTS
OIL & GAS DISTRICTS
CITIES
NOTE
COMBINED SYMBOLS SHOW TWO OR MORE MINERALS OCCUR AT SAME LOCALITY
BORAX, SODA
COPPER, ZINC
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
MENDOCINO
GLENN
BUTTE
SIERRA
NEVADA
COLUSA
YUBA
PLACER
LAKE
SUTTER
EL DORADO
SONOMA
YOLO
ALPINE
NAPA
SOLANO
SACRAMENTO
CALAVERAS
MARIN
SAN JOAQUIN
TUOLUMNE
MONO
STANISLAUS
MARIPOSA
SAN MATEO
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
SAN BENITO
FRESNO
INYO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
PACIFIC
OCEAN
NEVADA
ARIZONA
MEXICO

CONTENTS

PLATES

ECONOMIC ASPECTS OF MERCURY PRODUCTION IN CALIFORNIA

By C. R. King *

OUTLINE OF REPORT

ILLUSTRATIONS

ABSTRACT

Mercury is a metal of comparatively limited usefulness and demand; but is indispensable in most of its uses. Mercury deposits are notoriously irregular, and it is difficult to block out large reserves ahead of stoping operations. California has always been the principal producer of mercury in the United States, and has contributed from 50 to more than 80 percent of the total United States production. The United States production of mercury has always supplied domestic demand when the price of mercury was above $100 per flask, but imports from Spain and Italy have increased in direct ratio to drop in selling price below this figure. It is probable that future California production of mercury, even at high prices and with a stable market, will not exceed a rate of about 30,000 flasks per year. Under present conditions, California producers must receive from $100 to $125 per flask and must be assured of a stable market over a period of years to continue mining operations, with adequate exploration and development programs. Mercury, however, is a strategic metal, and the price and stability of the market are entirely dependant upon government policy.

INTRODUCTION

In many respects, mercury occupies a unique position among the metals. In many of its uses it is indispensable and no other substance can satisfactorily be substituted. On the other hand, mercury has a distinctly limited use, because of its properties or its comparative rarity and relatively high price. Mercury deposits are notoriously irregular in outline and the ore bodies are spotty both in distribution within the deposit and in grade within the ore body. Difficulty is generally experienced in blocking out large ore reserves of known assay and tonnage, and cost of production varies greatly in different mines. On the other hand, the reduction of the ore to refined metal is relatively simple compared to the metallurgy of most other metals.

From the standpoint of employment, only a few hundred men are engaged in mining and processing mercury in the United States; and the total volume of trade in mercury is small in comparison with most industries. New uses for mercury that would result in an expanded market are few, and substitutes are eliminating two or three of the former outlets for the metal. The widely publicized use of mercury in mercury boilers for the generation of power has not and will not consume more than a small fraction of the normal production, unless mercury is sold at approximately $40 per flask. The invention of the new dry cell battery

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* Associate Metallurgical Engineer, California State Division of Mines. Manuscript submitted for publication March 3, 1948.

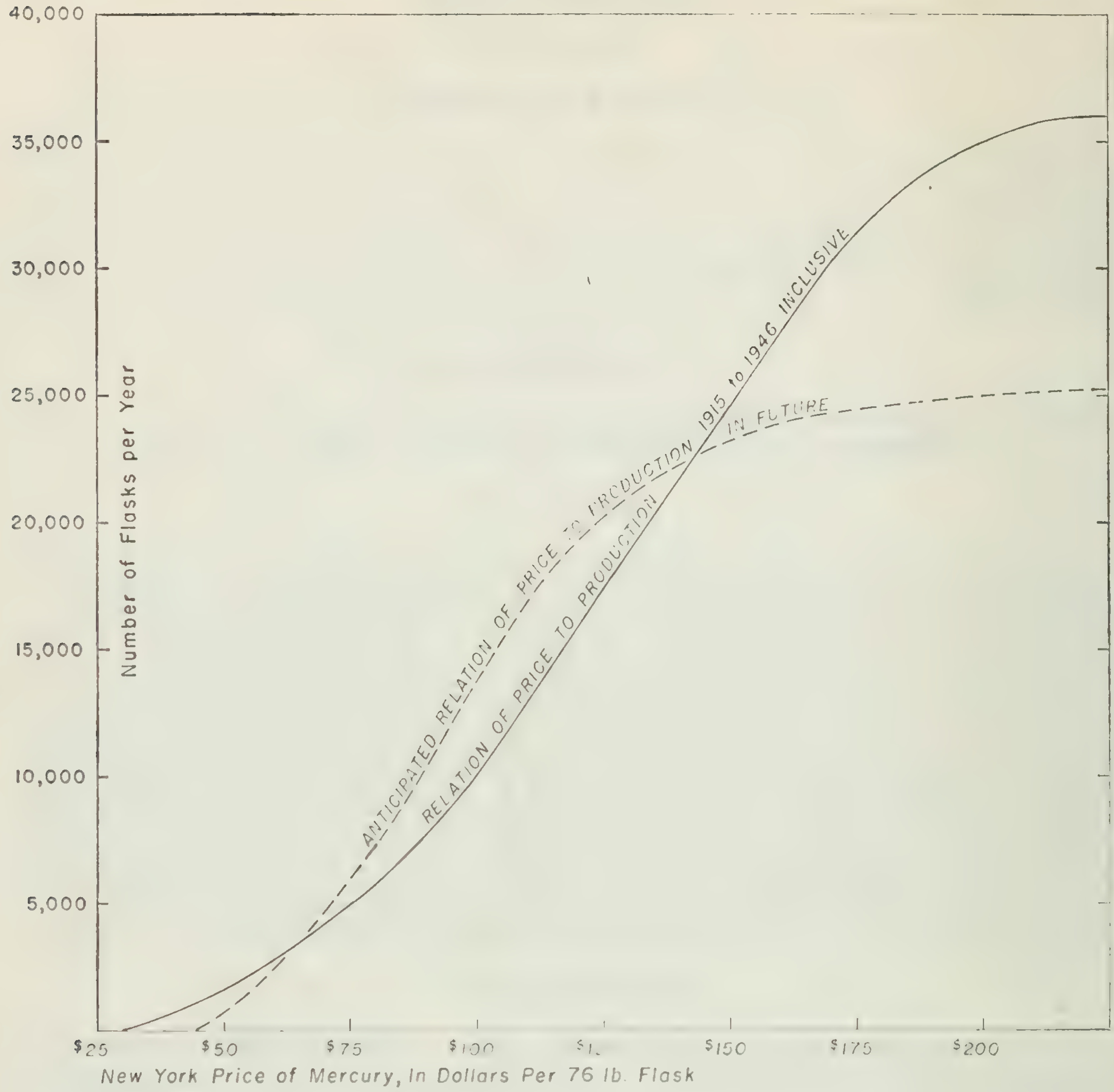

FIGURE 1. Production, consumption, and price of mercury

using mercury is perhaps the most important new use for the metal discovered in recent years. The demand for mercury, however, will probably continue to increase at about the same ratio to national income and population as formerly.

Since 1850 California has always produced more than half of the total output of mercury in the United States. Prior to 1915 the California production exceeded the United States consumption of the metal, and much of the output was exported. This condition was largely the result of intensive exploitation of the great bonanza ore bodies of the New Almaden district; and during this era production of mercury had little relation to United States consumption or selling price. After the relative exhaustion of these high-grade ore bodies (about 1915) and the formation of the International Mercury Cartel, mercury mines in the United States supplied the market without imports from foreign sources only when the New York selling price of mercury reached or exceeded $100 per flask of 76 pounds. California mines have contributed from 50 to 80 percent of the total United States production from 1915 to date.

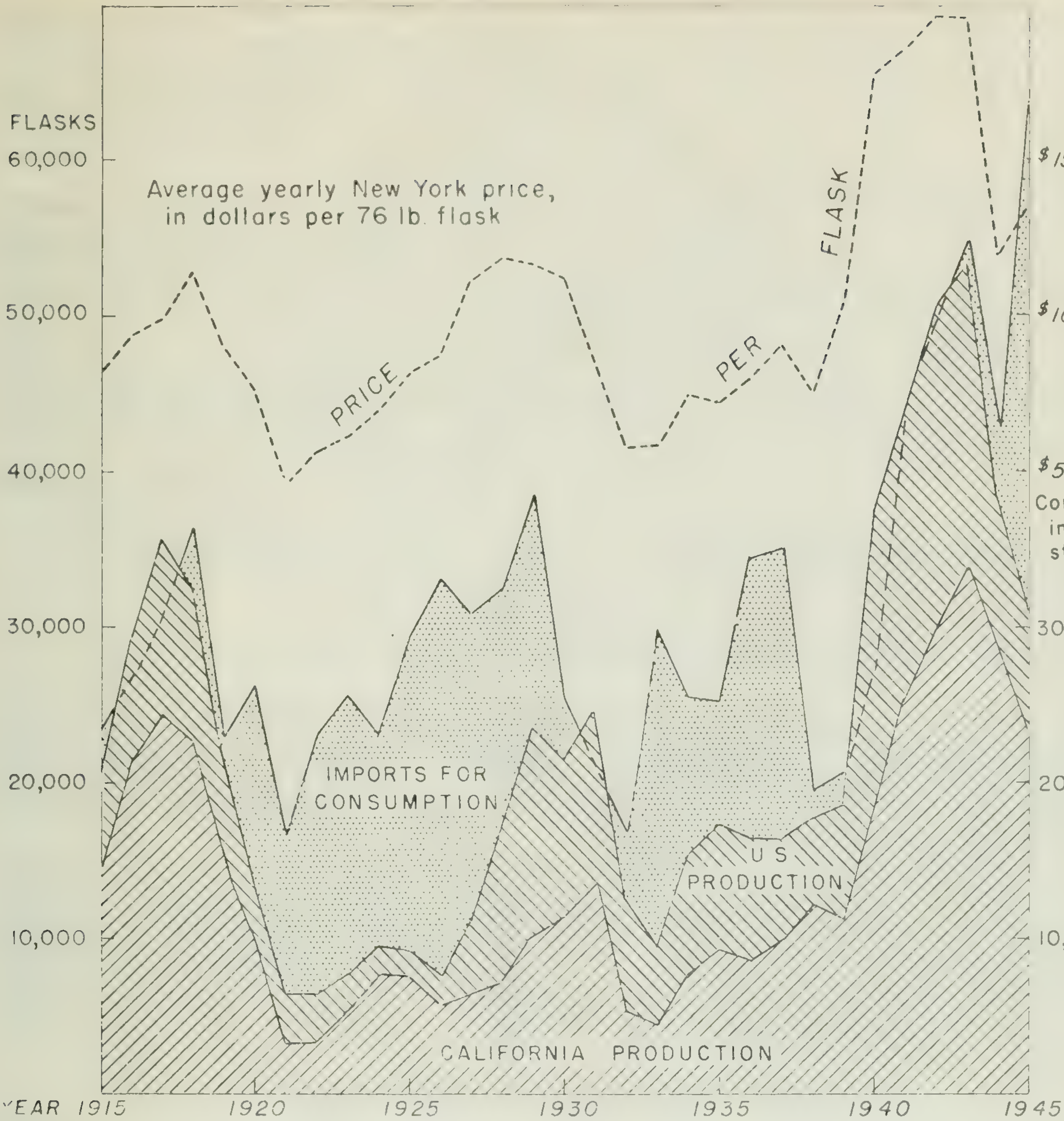

FIGURE 2. Relation of California mercury production to price.

PAST PRODUCTION AND PRICES

The following conclusions may be drawn from available statistical data for the period 1915-45 (see figs. 1 and 2):

(1) United States production has fluctuated sharply with selling price but has supplied domestic needs (consumption) whenever the New York selling price of mercury has exceeded $100 per flask. As the price dropped below $100, foreign imports increased in direct ratio to price drop.

(2) A definite time lag of 4 to 8 months has occurred in the increase of United States production in response to rising prices; however, the time lag in the downward adjustment of United States production to falling price is much shorter. Mercury is much more sensitive to price fluctuations than most metals, and the time lag between price variation and corresponding increase or decrease in production is much less than is the case with most other metals.

(3) In the past when the selling price of mercury was above $175 per flask (approximate price stimulating all-out United States production), the apparent maximum productive capacity of the California

mines has been approximately 35,000 flasks per year. There is some indication that, even with this price as an incentive, the maximum productive capacity of the mines in California cannot again reach 35,000 flasks per year, but may reach 25,000 to 30,000 flasks per year, if the selling price remains above $175 per flask for a reasonable time.

(4) In the past, California production dropped to approximately 8 or 10 percent of the maximum when the selling price dropped to $60 per flask or less. Production at selling prices between these extremes may be plotted and follows a fairly smooth curve (see fig. 2).

(5) If 1915 (when California produced 67 percent of the total United States production and the price was approximately $80 per flask) is taken as a base (index 100), the following approximate trends hold:

	Percent per year
Population in the United States has increased	1.32
National income has increased	5.00
Domestic consumption of mercury has increased	4.78
Domestic production of mercury has increased	5.24
New York average price for mercury has increased	3.75

The above average yearly rates of increase were of course subject to wide fluctuations, but weighting these fluctuations to straight lines and using 1915 as a base, we find that the slopes of the lines indicate the above average percentage increases.

That the average yearly rate of increase in the selling price of mercury has not kept pace with average rise in national income, average domestic consumption of mercury, or United States production, is notable. The principal reason for this is the pressure of foreign imports as regulated by the International Mercury Cartel.

PRESENT PRODUCTION AND TREND

In 1946 total United States production of mercury was 25,200 flasks. Imports were 23,062 flasks, and indicated consumption was 30,800 flasks. Average price for the year was $98.24, but there was a steady decline during the year from $103.82 in the first quarter to $90.90 in the last quarter. Relatively heavy imports, some dumping of mercury (captured in Axis countries) on the market, and the uncertainties regarding government policy with respect to foreign imports and government stockpile buying, accounted for this decline. During the year California produced 17,804 flasks (77.5 percent of United States total) which is approximately 8,000 flasks more than would be expected at an average price of $98 per flask. This may be accounted for by normal lag between price drop and production, plus temporary lower costs attained by some of the major producers. The present price trend and unstable market are reflected in the 1947 production of mercury in California, which is estimated to be 15,000 flasks or less.

The belief of California mercury producers is that with present costs and price index (first quarter 1947), a selling price below $100 per flask will prevent development and exploration and shut down all but one or two of the lowest cost mines in the state; and that even these will be forced to curtail to the point of minimum operations required to maintain mines and equipment. It is agreed that, in order to maintain a healthy industry with the necessary exploration and development to keep

ore reserves ahead of production and to mine the notoriously spotty ore bodies in the most economical manner, a selling price (or a return to the operator by subsidy or otherwise) of a minimum of $125 per flask (at present price index) is necessary, with increase or reduction as labor and other costs fluctuate with the price index.

Mercury is one of the critical strategic minerals, essential in time of war, of which the known United States reserves are definitely limited. For this reason, the future of the marketing and production in the United States will not follow ordinary economic laws but will be strongly affected by security policy, political expediency, and foreign supplies. From the standpoint of present national policy, it would probably be ideal to have all known deposits developed and delineated; to have standby equipment and reduction plants idle but capable of going into capacity operation with skilled crews on short notice; and to supply current consumption in the country exclusively by foreign imports. Unfortunately, this ideal is not practical, for the obvious reasons that mine openings require constant maintenance by skilled men; and the operation of reduction plants requires skilled crews intimately familiar with the particular plants and different types of ore treated therein. To recruit and train the necessary operating forces for mercury mines and reduction plants on short notice and after the former operators have lost their skills, would result in a very long time lag and defeat the primary object of conservation of our mercury resources. Further, the cost of maintaining idle mines and reduction plants in operating condition would be prohibitive. The apparent objectives of present government policy with respect to the strategic minerals are: (a) To create and maintain large mined and processed reserves or stockpiles of mercury (and other strategic metals), the purpose of such stockpiles being to take up the time lag between a sudden critical need and a corresponding increase in production of new metal; (b) To attempt, by every means including various subsidy plans, to maintain a small but healthy strategic mineral industry with a force of skilled men engaged in production and capable of rapid expansion in time of need; (c) To encourage the use of foreign supplies of mercury and other strategic metals in our current economy; (d) To encourage exploration for and development of new deposits of these minerals.

From the standpoint of the mercury producers in California, the practical applications of the foregoing general policy have to date had the opposite effect from that intended. Falling price and uncertainty regarding government tariff and stockpile policy have resulted in the mining of the highest grade ore, serious curtailment or abandonment of development and exploration, and complete abandonment of some mines with consequent flooding and loss of mine openings. The possible removal or reduction of the present tariff on mercury is a relatively minor factor in comparison with the disposition of foreign and captured stocks of mercury; the general question of the government stockpile of mercury; and possible subsidy in some form for the production of mercury. Tariff protection to insure a domestic price of about $125 per flask (at present index), plus assurance that this policy would continue for a 10-year period or more, would result in a healthy industry capable of supplying the United States needs for at least that period. This, however, would mean doubling the present tariff, and would be a complete

reversal of present foreign policy with respect to reciprocal trade treaties, as well as a partial defeat of the policy of conservation of reserves of strategic metals within the United States. For these reasons a stable price for mercury above $100 per flask resulting from tariff protection alone probably cannot be expected, and mercury producers and the national interest must look elsewhere for a solution to the problem.

Several methods of assuring a small but healthy domestic mercury industry have been proposed, all of which are based on some kind of a subsidy (except the method of outright tariff protection, which assures a sound industry and also results in appreciable revenue to the government). Among these methods are:

(a) An outright subsidy paid on the basis of production, as in the case of the premium price plan formerly in effect on lead, zinc, and copper. Many objections to this method have been cited, one of which is that such a subsidy would lead to accelerated exploitation rather than conservation of our mercury resources.

(b) A plan favored by the Munitions Board, which involves subsidizing unmined but fully developed reserves. Basically, this method would require that a mercury producer have a going concern and keep a reduction plant in operation, but that a subsidy based upon a percentage of the value of the measured unmined ore reserves would be paid to the producer (instead of subsidizing current production). Although some complications are involved in arriving at a workable formula for this type of subsidy, the difficulties would not appear to be insurmountable; and the method would encourage exploration and development of mercury reserves and tend to discourage rapid extraction of these reserves.

(c) Outright control by the government of the price of mercury, with the establishment of quotas for foreign imports (and possibly domestic production) as dictated by political expediency. This might be done by placing an import duty (tariff) high enough to assure a price of roughly $100 per flask to the American producer and then by reciprocal trade agreements coupled with quota restrictions favoring any mercury-producing nation in which it was desired to establish dollar credits. Intelligent application of such a method might result in a relatively small and healthy domestic industry. The tendency to rapidly mine out reserves would be eliminated, and the "know-how" should be available to rapidly expand production when and if necessary.

The opinion of most of the mercury producers in California is against an outright subsidy based on production. They favor, however, any workable scheme that will stabilize the selling price of mercury over a reasonable period of time (5 or 10 years), at a level that will maintain a healthy industry. Under present conditions this level would be somewhat above $100 per flask (which would correspond to $70 per flask with costs comparable to 1915). The majority of California producers favor some modification of the method of control of price outlined in the foregoing under "c"; but would not oppose a workable plan to subsidize unmined reserves (plan "b"). They believe that, with a stable market at a level permitting a little profit reasonably assured over a 10-year period, the incentive to explore and develop possible mercury-bearing areas would result in a very appreciable increase in the known U. S. reserves

of mercury, and the industry would be in an excellent position to rapidly expand production in case of need.

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CURRENT AND RECENT MINING ACTIVITIES IN THE REDDING DISTRICT

By J. C. O'Brien *

OUTLINE OF REPORT

ILLUSTRATIONS

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* Mining Engineer, Redding district, California State Division of Mines. Manuscript submitted for publication February 2, 1948.

ABSTRACT

The Redding district of the California State Division of Mines includes an area of 36,678 square miles within the boundaries of 12 counties. It is bordered on the north by the state of Oregon, on the east by the state of Nevada, on the west by the Pacific Ocean, and, within the state, on the south and east by Plumas, Butte, Sutter, Yolo, Napa, and Sonoma Counties. It has a great variety of physiographic and geologic features. Seven of the eleven geomorphic provinces of California are either wholly or partly within its borders. Commercial production of some 35 mineral substances has been recorded from deposits within the district. At the time this article was written, 15 mineral substances were being produced. All of the manganese and most of the chromite and quicksilver deposits were shut down shortly after the close of the war. Production of copper and zinc was low because deposits had been mined without developing new reserves. The scarcity and high cost of labor, equipment, and materials is a very great handicap to quartz mining. Where they can be used to advantage, bulldozers and draglines are employed in open-pit mining.

A great demand exists for materials used in building roads and in concrete construction. Sand and gravel pits are being worked in every county. Many plants for manufacturing concrete building blocks have been erected at gravel pits. The pumice deposits in the Glass Mountain area in Modoc and Siskiyou Counties have been worked to supply the demand for pumice for use as a light-weight concrete aggregate and as an insulating material.

The U. S. Bureau of Mines' pilot plant at Shasta Dam is making electric furnace products from materials that can be produced in this district. Geologists of the U. S. Geological Survey are mapping the western half of the "Shasta copper belt" and their maps and reports will be a very great help in the search for new deposits. Development of important zinc sulphide replacement ore bodies in the shales adjacent to the rhyolite contact in the Afterthought mine at Ingot should encourage prospecting for similar deposits in that area.

COLUSA COUNTY

Miscellaneous Stone

Paul Entremont of Colusa operates a gravel pit on the Wolfram Ranch south of Princeton. Three 5-cubic yard dump trucks are loaded with a P & H dragline equipped with a bucket of half a cubic yard capacity. The pit run gravel is sold for concrete aggregate.

Jean Godon of Colusa operates a gravel pit on the Indian Reservation between Colusa and Princeton. The gravel is loaded on three 5-cubic yard dump trucks with a Scoopmobile loader and is delivered in the Colusa area. Godon also loads red-colored gravel from a pit about 2 miles southwest of Williams. It is used on roads in that area.

McKasson Brothers gravel pit on the west bank of the Sacramento River at Princeton is owned and operated by Clarence W. and D. O. McKasson, Route 1, Box 116, Colusa. The gravel is dug about 10 feet deep with a Caterpillar "30" tractor equipped with a Pushloader fitted with a bucket of half a cubic yard capacity. They also have a Bear Cat dragline with a 25-foot boom and a three-eighths cubic yard bucket. Pit run gravel is loaded on two 4-cubic yard or two 2½-cubic yard trucks for deliveries. It is used mostly for concrete aggregate. The brothers operate the pit without additional help and deliver about 20 cubic yards of gravel per day in the Colusa area.

Shaver and Rabbit of Princeton operate a gravel pit on the west side of the Sacramento River a few miles south of Princeton on land owned by the Mayfair Packing Company. Trucks are loaded with a Scoopmobile and a Caterpillar "30" tractor equipped with a Pushloader.

Pit run gravel is delivered in the Colusa area and used mostly for concrete aggregate.

DEL NORTE COUNTY

Chromite

French Hill (Tyson) mine is located on patented land in sec. 6, T. 16 N., R. 2 E., H. It is owned by Tyson Chrome Mines, Ltd., a partnership composed of Benjamin C. Mickle, general partner, and A. W. Ekstrom and Frank J. Grogan, limited partners; offices are at 406 Montgomery Street, San Francisco. The property had a recorded production of more than 4,000 tons during World War I. From June 1942 to August 1946 seven lenses of chromite were developed and mined at this property by the Tyson Company. They yielded about 20,000 tons of ore averaging 44 percent Cr_2O_3. The chromium-iron ratio was about 2.5 to 1. Shipments were made by truck to Metals Reserve Company stockpile at Grants Pass, Oregon. The lenses occurred in sheared and brecciated serpentine and were separated by only a few feet in some instances. The uppermost ore body was mined by an open cut and by side sets from an adit driven N. 20° W. for 30 feet. The lens was about 60 feet long, 30 feet wide, and 8 feet thick. About 60 feet southwest of the portal of the adit a 35° incline shaft was sunk 35 feet in a N. 50° W. direction. A crosscut driven west 20 feet from the bottom of the shaft hit the intermediate ore body which was about 75 feet long, 60 feet wide, and 6 feet thick. The lowest and largest ore body mined was developed by a shaft 115 feet deep inclined 70° W. The collar of the shaft was about 25 feet south of the 35° incline shaft. The 115-foot shaft was in ore from 25 to 60 feet. An adit driven N. 50° E. 175 feet to the shaft at the 55-foot level was in ore from 140 feet. The lens of ore was about 100 feet long, 70 feet wide, and 35 feet thick. It was mined by square-set stopes, timbered with 8- by 8-inch square timbers, and 7-foot posts were placed at 5-foot centers. The ground was heavy, and the sets had to be braced and filled close to the working face.

The U. S. Geological Survey [1] mapped this deposit in 1942-43, and in 1944 the U. S. Bureau of Mines drilled 14 diamond-drill holes from 80 to 140 feet deep. They are reported to have cut 17 feet of ore in one hole and 6 feet in another. Subsequent mining showed that some drill holes missed the chromite by only a few feet.

In August 1946 Tyson Chrome Mines, Ltd., sold its mining equipment and leased its Del Norte County mines to Sam J. Wilson of Crescent City, care of Patrick Creek Tavern. The property was diamond drilled and several new ore bodies were located—one 70 feet long and 30 feet thick, another 30 feet long and 18 feet thick. After mining and shipping about 2,000 tons to San Francisco, Seattle, and Tacoma buyers, Wilson and his associates decided to mine the remaining ore bodies by an open cut. The contour of the ground and the sheared and brecciated character of the overburden are favorable for a hydraulic operation. In October 1947, four men and a bulldozer were employed under the supervision of E. A. Carlson, digging a ditch to carry water from a swamp on French Hill. They will have about a 250-foot head at the pit and intend to use a No. 3 giant with a 2-inch nozzle to wash the overburden into the gulch.

[1] Wells, F. G., Cater, F. W. Jr., and Rynearson, G. A., Chromite deposits of Del Norte County, California: California Div. Mines Bull. 134, pt. 1, pp. 47-52, 1946.

Quicksilver

Shults Brothers quicksilver mine (Webb, Patrick Creek, Wilmot) includes eight unpatented claims in sec. 20, T. 18 N., R. 3 E., H., owned by David Webb of Kerby, Oregon. The property has been operated by a succession of lessees since July 1942, including H. C. Wilmot, Sutherlin, Oregon; Bert Avery, Patrick Creek via Crescent City, California; Ed and Oscar Hanno, Box 242, Cambria, California; and since October 1946 by I. N. and M. D. Shults, Box 127, Medford, Oregon. Wilmot built a road to the property in July 1942 and drove an adit S. 1° W. for 40 feet. The first 12 feet cut through a yellow and tan meta-andesite lying above a fine-grained bluish-gray trap rock. At 35 feet a fine-grained gray dike 3 feet wide strikes N. 70° E. and dips 80° N. above a dark-gray peridotite. Native quicksilver and cinnabar occur in vugs and seams in the hard gray trap rock and in seams in the meta-andesite above the dike. Native quicksilver was plentiful. At 35 feet from the portal, a drift was driven west for 40 feet, then offset about 6 feet south to the peridotite. It was continued along the peridotite footwall in a S. 65° W. direction for 25 feet in a fine-grained gray rock that contained some cinnabar. A crosscut driven northeast from the drift at the offset is in waste.

A vertical 4- by 6-foot shaft 35 feet deep was sunk about 10 feet north and 5 feet west of the portal of the adit. A crosscut was driven south for 35 feet at the bottom of the shaft, thence S. 60° W. for 15 feet to ore, and continued in ore for 20 feet. The shaft was full of water when visited, and the present (October 1947) operators are driving a new adit whose portal is about 100 feet northeast and about 35 feet lower than the collar of the shaft. The new adit was driven N. 20° W. and was 90 feet long on October 23. It will be turned southwest to tap the ore at the bottom of the shaft.

Bert Avery shipped some sorted ore to the Mountain King mine at Gold Hill, Oregon, for treatment in 1943. In 1945, Ed and Oscar Hanno installed a wood-fired four-pipe retort and produced some quicksilver. They found some additional ore on the hill about 200 feet southwest and 75 feet higher than the shaft at the adit portal and sank about 26 feet along a slip striking N. 53° E. and dipping vertically. This may be the same slip along which the ore was found in the adit and the crosscut from the shaft. The soft reddish-brown clayey material is 4 to 5 feet wide above the footwall and assayed up to 80 pounds of quicksilver per ton. The hanging wall is a tan meta-andesite; some cinnabar is found in the seams for a short distance above the soft brown ore.

The ore at the portal of the original adit was mined back to the dike. The pipe retorts lost a large percentage of the quicksilver and have been discarded. In October 1947, five men were employed installing a Lacy rotary furnace 30 feet long and 30 inches in diameter. The furnace will burn fuel oil and will be rotated at 2 revolutions per minute. The mercury vapor and furnace gases will be drawn through the furnace by an American blower and through an 8- by 8-inch Sirocco-Type D dust collector to 10 steel condenser pipes 16 inches in diameter and 24 feet long. The remaining gases from the condensers will pass through a wooden tank 8 feet in diameter and 8 feet high to collect the soot before the gases go to the air through the stack. The furnace will have a capacity of about 30 tons per 24 hours. A new cook house and a bunk house have been built to accommodate the crew. M. D. Shults is in charge of the operation.

Miscellaneous Stone

Basalt Rock Company, Napa, California, Ernest Isley, superintendent, quarried rock from Preston Island to build jetties for Crescent City harbor. The jetties have a base 150 feet wide, rise about 30 feet above the sea, and are 20 feet wide at top. They will be about 1,000 feet long, and 600 feet remain to be built.

The rock is a fine-grained heavy greenstone. Coyote holes were drilled with drifters using a 4-foot burned cut round in a 3- by 4-foot section. One coyote hole was driven 55 feet at right angles to the face about 120 feet above the toe. Tee drifts were driven 90 feet to the left and 65 feet to the right. Seven powder pockets along the coyote drifts were loaded with about 12 tons of 60 percent bag powder. About 100,000 tons of rock is estimated to have been broken in blasting two coyote holes. The broken rock is classified as ''A'' rock, 5 to 15 tons; ''B'' rock, 3 to 7 tons; and ''C'' rock, 5 pounds to 4 tons. In building the jetty, the ''C'' rock was placed first, then the ''B'' rock, and finally a covering of ''A'' rock. The ''B'' and ''C'' size rocks were separated and loaded with two 2½-cubic yard and one 2-cubic yard Northwest shovels onto Euclid dump trucks and hauled to the jetty where some were dumped over the end and others were dumped into 1,000-ton steel barges from a ramp. The barges were towed into position and unloaded with a Northwest 95 crane equipped with either an orange-peel or a clam-shell bucket. The ''A'' size rock was loaded onto trucks with a Northwest 80 shovel converted into a crane. Some rocks were handled with slings, but more often steel pins 2 inches in diameter and 10 inches long were placed in jackhammer-drilled holes to hold the crane slings. From 3,000 to 3,500 tons of rock were moved in two 10-hour shifts. John Meloni was quarry superintendent and Alonzo Crawford foreman. About 115 men were employed from July to October 1947, when the work was closed down for the season.

Crescent City Rock and Sand Company, Bud Smith, owner, has a lease on a gravel pit on the west bank of the Smith River about half a mile north of the bridge in sec. 2, T. 17 N., R. 1 W., H. The gravel is pushed with an R.D. 4 Caterpillar bulldozer into a steel bunker 10 feet long, 10 feet wide, and 12 feet deep, from which it is drawn onto a 30-inch belt conveyor about 55 feet long and delivered to the hopper of a Diamond Rock Works rock crusher. From the hopper the material is drawn onto a 30-inch conveyor belt 46 feet long and delivered to a double-deck shaking screen fitted with 1½-inch and ¾-inch screens. The gravel over 1½ inches in size slides to a 20- by 19-inch jaw crusher and is crushed to ¾-inch. The material remaining on the ¾-inch screen is delivered to a pair of 30- by 36-inch rolls set at half an inch. The product from both the jaw crusher and the rolls drops on a 28-inch conveyor belt 30 feet long and is delivered to a rotary wheel elevator 9 feet in diameter, which discharges it on the first 30-inch conveyor belt, which returns it to the vibrating screens. The minus ¾-inch material drops on a 28-inch by 30-foot conveyor belt for delivery to trucks or stockpile.

The power for the plant is obtained from a Buda 190-horsepower diesel engine. Equipment includes a Northwest Model-25 dragline, which has accessory fittings to convert it into a 1-cubic yard power shovel, and an 8½-foot by 38-inch Iowa double-deck screen washing plant. In October 1947 only minus ¾-inch material was being produced and it was all being

used for road material. W. H. Sutton, foreman, was in charge of a five-man crew.

GLENN COUNTY

Miscellaneous Stone

L. G. Madsen and F. A. Cramer, 246 South Plumas Street, Willows, operate a gravel pit about 3 miles northeast of Willows on the North Fork of Willows Creek. Gravel is dug 16 to 20 feet deep with a Model 150 P & H dragline having a 30-foot boom and fitted with a bucket of half a cubic yard capacity. It is loaded on two dump trucks of 5 cubic yards capacity for delivery to customers. About 1,250 cubic yards of pit run gravel is sold per month by the partners, who work alone. It is estimated that half is used for concrete aggregate and half for roads and stock corrals.

Orland Sand and Gravel Company, E. B. Bishop and E. Thomas of Orland, partners, is producing sand and gravel and ready-mix concrete at its plant on the north bank of Stony Creek about $1\frac{1}{2}$ miles north of Orland. The gravel is dug 6 to 10 feet deep with a Bucyrus Erie power shovel equipped with a $1\frac{1}{4}$-cubic yard bucket and loaded into dump trucks of 4 cubic yards capacity. The gravel is dumped into a concrete hopper of 25 cubic yards capacity from which it is drawn by a Bodinson oscillating feeder onto a 24-inch by 280-foot belt conveyor and discharged over a 3- by 8-foot Niagara double-deck shaking screen. A water spray above the screen washes the silt from the material. Screens are changed to produce the required sized products and the screened materials are diverted by slides into six cylindrical concrete silo-type bins 20 feet in diameter and 30 feet high. The oversize is crushed through a pair of 22- by 40-inch Diamond rolls and returned to the screen. When fine sizes of materials are needed, the undersize from the screen is delivered to a 3- by 8-foot Stephens-Adamson double-deck screen fitted with $\frac{3}{8}$- and $\frac{3}{16}$-inch screens. Sand is flumed from this screen and dewatered by means of a sand wheel which discharges it into one of the concrete bins.

The materials stored in the concrete bins can be drawn onto a 20-inch belt conveyor running between the bins, and delivered either to railroad cars or to a four-compartment truck bunker having a capacity of 60 cubic yards.

The batching plant is located adjacent to the truck bunkers. It has three steel bins with a capacity of 21 tons. They are usually filled with $1\frac{1}{2}$- and $\frac{3}{4}$-inch gravel and sand which is delivered from the concrete bins by a belt conveyor. The desired proportions of sand and gravel can be weighed into a batching hopper of 21 cubic feet capacity, which is mounted on a trolley, and dumped into Ransome transit-mix trucks of 2 cubic yards capacity. The batch plant has a capacity of 40 cubic yards of concrete, which can be delivered within a 3-mile radius in 8 hours. Some trucks are loaded with pit run material with an HD-5 Allis Chalmers tractor shovel fitted with a 1-cubic yard bucket. Six men are employed at this plant. E. Thomas, one of the partners, is in charge.

HUMBOLDT COUNTY

Copper-Zinc

Copper Bluff Mining Company, A. W. Scott, president, George Russell, secretary-treasurer, Yreka Inn, Yreka, California, has a lease expiring in 1962 on 134 acres of land in the Hoopa Indian Reservation

in sec. 35, T. 9 N., R. 4 E., and sec. 2, T. 8 N., R. 4 E., H. A vein of zinc-copper ore has been uncovered in three shallow pits spaced about 100 feet apart on the hill above the highway. It is from $3\frac{1}{2}$ to $7\frac{1}{2}$ feet wide, strikes N. 7° E. and dips 15° E. Sphalerite, chalcopyrite, pyrite, and some quartz occur in a banded or laminated vein between a dark-gray shale footwall and a pyritic schist hanging wall. A sample assayed 0.014 of an ounce of gold, 0.31 of an ounce of silver, 3.6 percent copper, and 11 percent zinc. At a place about 3,500 feet northeast and some 300 feet higher than the discovery cuts, an adit driven 22 feet east cut $4\frac{1}{2}$ feet of vein striking N. 7° E. and dipping 12° E. The hanging wall is pyritic schist. No footwall was uncovered in the adit. A sample across $4\frac{1}{2}$ feet assayed $5.80 in gold, 6 ounces in silver, 1.10 percent copper, and 7.68 percent zinc. More quartz shows in the vein here than at the discovery cut.

An attempt was made to diamond drill the property in 1943, but the loose schistose formation caused much difficulty, and only two out of four vertical holes reached the vein. Hole No. 1, drilled about 110 feet east of the discovery cut and some 250 feet above the highway, was abandoned at 60 feet; hole No. 2, drilled to a depth of 170 feet, cored 7 feet of vein between 128 and 135 feet, which assayed 0.40 of an ounce of gold, 4.6 ounces silver, 4.4 percent copper, 12.7 percent zinc, and a trace of lead. Hole No. 3 was abandoned at 80 feet. Hole No. 4, drilled 90 feet south of hole No. 2, cored 5 feet of vein assaying 0.98 of an ounce of gold, 5.1 ounces of silver, 3.6 percent copper, and 8.5 percent zinc.

In November 1944, the Marsman Company of California equipped the property with an Ingersoll-Rand Model 370 air compressor and rock drills and reopened an old adit some 25 feet below the highway that had been driven S. 75° E. about 400 feet. At 215 feet from the portal, a single-compartment raise inclined 59° was driven S. 15° W. through a light-gray shale for 170 feet to a vein $3\frac{1}{2}$ feet wide, striking N. 7° E. and dipping 11° E. A drift was run 8 feet north on the vein. The Marsman Company was unable to acquire the property on satisfactory terms, and so withdrew. In 1947 the Copper Bluff Mining Company was formed, capitalized at 500,000 shares of stock with a par value of 35 cents, 250,000 shares of which were authorized for sale. In October 1947 two men were employed clearing brush for a camp site and prospecting the outcrop. Philip Toleman is superintendent.

Gold

Bondo mine (formerly Croton Bar and Markeson mine) includes unpatented land in $S\frac{1}{2}$ $NW\frac{1}{4}$, $W\frac{1}{2}$ $SW\frac{1}{4}$, and $NE\frac{1}{4}$ $SW\frac{1}{4}$ sec. 20; $W\frac{1}{2}$ $NE\frac{1}{4}$ $NW\frac{1}{4}$ sec. 29; and $E\frac{1}{2}$ $NE\frac{1}{4}$ sec. 30, T. 11 N., R. 6 E., H. The property is held by Allen E. Woodson, Silas S. Woodson, Carrie E. Woodson, Robert S. Woodson, Alice I. Woodson, George T. Woodson, Albert Cole Burlingame, and George E. Burlingame. The owners have made application for 3 cubic feet of water per second to be diverted from Wilson Creek in $SE\frac{1}{4}$ $SW\frac{1}{4}$ sec. 17, T. 11 N., R. 6 E., H. The property consists of bench gravels above the Klamath River about 2 miles north of Orleans. The gravel stands about 40 feet high above a slate bedrock. The property has been idle since 1940, but in June 1947 E. A. Rice obtained a lease from the owners. He has had three to five men employed clearing the

surface of brush and trees and repairing ditches and flumes so that mining may be resumed this winter.

Klamath Dredging Company, Guy Standifer, president and general manager, San Bruno, California, has a bucket-line dredge on the Klamath River at Stony Bar near Orleans in sec. 31, T. 11 N., R. 6 E., H., on ground leased from R. F. Felchlin. The dredge was built by the Walter W. Johnson Company of San Francisco and has 27 steel pontoons, making a hull 50 by 110 feet. The digging ladder has 82 buckets of 6 cubic feet capacity, driven by a 125-horsepower motor to discharge 28 buckets per minute. It is capable of digging 32 feet below water level. The trommel is 6 feet in diameter and 40 feet long and has 32 feet of $\frac{3}{8}$- to $\frac{5}{8}$-inch perforations. It is driven by a 50-horsepower motor. There are seven 34-inch by 14-foot transverse sluices in a double-deck arrangement, and five downstream sluices fitted with rubber-covered wooden Hungarian riffles on each side of the trommel. Water is supplied by a Byron-Jackson 10-inch high-pressure centrifugal pump driven by a 60-horsepower motor, and by a 12-inch Byron-Jackson low-pressure centrifugal pump driven by a 35-horsepower motor. The winch is driven by a 50-horsepower motor. The stacker belt is 30 inches wide and 100 feet long between pulleys. Power is supplied by two 275-horsepower Atlas Imperial diesel engines direct-connected to two 480-volt, 175-kilowatt generators. The spud is 52 feet long and weighs 19½ tons. The gravel was tested by shafts and drill holes spaced at 200- and 400-foot intervals. It is 42 feet deep above a medium-soft slate bedrock. The water for the dredge pond is pumped by an 8-inch centrifugal pump driven by a 25-horsepower General Electric motor. Equipment includes two General Electric 300-ampere arc welders and an RD4 Caterpillar bulldozer.

The boat has been idle since 1942 except for lengthening and strengthening the digging ladder brackets and general overhauling. The normal operating crew will be 25 men. F. E. Dunn, Orleans, is dredgemaster.

Nelson mine (Murray) includes 117.50 acres of patented land in secs. 4 and 9, T. 11 N., R. 6 E., H., owned by J. A. Harris of Los Angeles. Ed Nitsche of Somes Bar operated the property in a small way in 1946, using a self shooter from the reservoir. Water is obtained from Rosaline, Mud, and Ten Eyck Creeks. The gravel is 15 to 20 feet deep above a serpentine bedrock and includes many boulders. Three men are employed cleaning ditches, laying pipe, and preparing the property for operation this winter.

LAKE COUNTY

Mineral Water

Grizzly Spring in sec. 3, T. 13 N., R. 6 W., M. D., is owned by S. G. Mason of Clearlake Oaks. An alkaline water containing sodium chloride, magnesium and sodium carbonates, and other minerals flows about 2 gallons per minute. It is piped into a bottling house where 12-ounce bottles are filled by a Shields bottling machine. The machine has a capacity of 60 dozen bottles per hour. Carbonated beverages of popular flavors are also bottled at this plant. The bottles are packed in cardboard cartons holding 24 bottles and are sold through mail orders and stores in the Clear Lake area. The plant is operated by the owner, who works alone.

Quicksilver

Sulphur Bank mine on the southeast shore of Clear Lake in sec. 6, T. 13 N., R. 7 W., M. D., is owned by the Bradley Mining Company, 425 Crocker Building, San Francisco. Mr. A. F. Wolbert is in charge at the mine. The property has been idle since 1945 except for churn-drill prospecting. Twelve men were employed from October 1 to November 10 retorting about a thousand tons of ore which remained in the ore bin. The equipment at the plant will be inventoried for sale. The property was described by Averill in an earlier report.[2]

Miscellaneous Stone

Aggrelite Company, owned by John C. McFadyen and William Spirack, 1734 Webster Street, Oakland, operates a concrete-block plant at the Sulphur Bank mine on the southeast shore of Clear Lake in sec. 6, T. 13 N., R. 7 W., M. D. Mine-dump material crushed and screened to minus one-half inch is delivered to the steel bins above the plant by a belt conveyor from the Pyzer aggregate plant. The aggregate is drawn from the bins into a measuring hopper which holds six bags of aggregate and one bag of cement. It is mixed in a conical cement mixer driven by a four-cylinder Le Roi gasoline engine. Water is added to give the desired consistency and the concrete is discharged into a steel hopper from which it is fed into a Flam vibrating-block machine by a hydraulic feeder. The machine makes three 4- by 8- by 16-inch blocks at a time and has a capacity of about 2,000 blocks in 8 hours. Six men are employed. John C. McFadyen is in charge at the plant.

Francis M. Frazell and Frank and Kennett Evans of Kelseyville operate a gravel plant on Kelsey Creek on ground leased from H. A. Smith. The gravel is dug with a Sauerman slackline equipped with a bucket of half a cubic yard capacity. A $\frac{7}{8}$-inch wire rope runs through blocks suspended from two steel towers 73 feet high, and the bucket is pulled by an American double-drum hoist powered by a 24-horsepower electric motor. The gravel is discharged into a 12- by 12-foot steel hopper and is fed to a four-deck vibrating screen fitted with $1\frac{1}{4}$-, $\frac{3}{4}$-, $\frac{7}{16}$-, and $\frac{1}{8}$-inch mesh screens. The material is washed on the screen by water sprays, and the sand is dewatered in a Dorr drag classifier. There are five steel storage bins of 25 cubic yards capacity each for the screen products. Rocks more than $1\frac{1}{4}$-inch in size are crushed in a 10- by 16-inch jaw crusher and returned to the screen by a bucket elevator. About 125 to 150 cubic yards of material are handled per day. There are three 4-cubic yard dump trucks for delivering the sand and gravel. Gravel sells for $1.50 per cubic yard at the plant. The three partners operate the plant without additional help.

Lang Brothers sand and gravel pit is located on Kelsey Creek about 7 miles north of Lakeport. Gravel is pushed into a wooden hopper with a D-4 Caterpillar tractor bulldozer or loaded into trucks with a D-2 Caterpillar loader equipped with a bucket of half a cubic yard capacity. The gravel is drawn from the hopper to an 18-inch by 50-foot belt conveyor and discharged over a double-deck vibrating screen fitted with one-inch and half-inch screens. The gravel is washed on the screen by a water spray. Oversize slides to a stockpile, and the 1-inch size, half-inch size,

[2] Averill, C. V., Lake County: California Jour. Mines and Geology, vol. 43, pp. 34-37, 1947.

and sand are stored in separate bins, from which they are loaded onto trucks for delivery. There are two dump trucks, each of 4-cubic yard capacity. One man was working at the plant when it was visited. It has a capacity of about 100 cubic yards per day.

Pyzer aggregate plant, owned and operated by E. H. Pyzer of Lakeport, is located at the Sulphur Bank mine on the southeast shore of Clear Lake in sec. 6, T. 13 N., R. 7 W., M. D. Broken rock on an old mine dump is pushed into a wooden bunker of 10 cubic yards capacity by a Model "M" Allis-Chalmers bulldozer. A 3- by 4-foot apron feeder beneath the bunker loads a 16-inch conveyor belt which is 40 feet long and mounted on a portable steel truss. The rock is discharged over a 24-inch by 8-foot shaking screen having 4 feet of ⅛-inch, and 4 feet of ½-inch screen. The oversize slides to a 10- by 20-inch Universal jaw crusher and the crushed product is returned to the screen by a bucket elevator. The undersize from the screen slides to a 20-inch by 45-foot conveyor belt and is delivered to the steel bin of the Aggrelite Company block plant. Power is supplied by an Allis-Chalmers V-40 power unit. Accessory equipment includes a Scoopmobile with a three-quarter cubic yard bucket and two 8-cubic yard dump trucks. Pyzer was operating the plant alone on November 6, 1947.

LASSEN COUNTY

Gold

Blue Bell group (Harris and Musgrove) includes three patented claims in secs. 24, 25, T. 39 N., R. 11 W., M. D., owned by C. L. Musgrove, Box 391, Susanville, California. The principal development has been on the Boyd vein, which is a shear zone 10 to 15 feet wide in quartz diorite with limonite-stained quartz seams striking N. 45° E. and dipping 85° SE. Much of the vein matter consists of silicified fragments of quartz diorite. There are many narrow bands of minute quartz crystals. The vein can be traced for several thousand feet and it has been developed and mined by many open cuts, shallow shafts, and drifts on the vein from cross-cut adits. Portions of the Boyd vein in the adjoining Arkansas claim are reported to have produced $200,000 in free gold.[3] No record of the early production from the Blue Bell group exists. Recent development consists of a 40-foot vertical shaft sunk on a vein 3 feet wide, that strikes N. 45° E., in quartz diorite. The vein material is similar to that of the Boyd vein, consisting of angular silicified fragments of quartz diorite, narrow seams of white quartz, and many bands and vugs lined with minute quartz crystals. The quartz is stained yellow and brown by limonite. Musgrove has been working alone sinking the shaft and has saved several tons of ore for treatment.

Lassen Eagle Mining Company (Hayden Hill Gold Corporation, Lassen Mining Company), is a California corporation wholly owned by the Golden Eagle Mining Company, which is incorporated in the State of Washington. C. C. Anderson, president, and C. O. Dunlap, managing director, have offices at 417 Symons Building, Spokane, Washington. F. H. Brown, Adin, California, is manager of operations at the mine on Hayden Hill. The company holds 10 claims on Hayden Hill in sec. 36, T. 37 N., R. 9 E., M. D.

Gold occurs in a rhyolite breccia and is associated with narrow quartz stringers and thin red seams. Gray, powdery sugar quartz is plen-

[3] Averill, C. V., Lassen County: California Div. Mines Rept. 32, p. 411, 1936.

tiful. A thousand samples taken from the outcrop along a shear zone in rhyolite on the Golden Eagle, Minnie Bell, and Seven Preachers claims, averaged $4.21 in gold according to Mr. Brown.

On the Golden Eagle claim, the shear zone was sampled by running the material mined from two trenches 8 feet wide, 8 feet deep, and 250 feet long, through a sampling mill. The rock was drilled and blasted and pulled into a hopper with a slusher. Dump trucks were loaded from the hopper and the ore hauled to the sampling mill where it was dumped over a grizzly with bars spaced at 1 inch. The oversize was crushed in an 8- by 12-inch Straub jaw crusher and combined with the undersize from the grizzly on a 16-inch by 35-foot conveyor belt. A 4-pound sample was cut from the belt each minute by passing a 6-inch conveyor bucket through the stream of ore. The cut sample was crushed to a quarter of an inch in a 6- by 8-inch Straub jaw crusher and dropped on a conveyor belt from which a second sample was cut. A 50-pound sample was cut for each 50 tons of material run through the sampler. Brown said that about 1,500 tons of samples taken from the shear zones 20 to 50 feet wide to a depth of 20 feet averaged $4.00 per ton in gold. Tests have indicated that 70 percent of all gold is contained in the 10 percent of material that will pass through a 40-mesh screen, and that a 98 percent recovery can be made by a 72-hour counter-current cyanide leach.

The old cyanide mill has been remodeled to screen out and reject all material over 40 mesh. Mine dumps will be milled first. They will be loaded into mine trucks with an Erie power shovel of 1-cubic yard capacity. The trucks will be dumped over a hopper from which the ore can be drawn onto a conveyor belt and delivered to a trommel screen 4 feet in diameter and 22 feet long, with ¼-inch holes. The material will be washed with sprays as it travels through the trommel. Oversize will be discharged on a tailing-belt and discarded as waste. Undersize will be delivered to a Straub revolving-wheel screen 60 inches in diameter and fitted with 40-mesh screens. Oversize will go to the tailing-belt and the undersize will be pumped to a storage settling tank 46 feet in diameter and 10 feet deep, from which most of the wash water will be recovered. The thickened material will then be pumped into a 10- by 10-foot steel cylindrical conditioning tank, where lime and cyanide will be added. It will then be pumped through a series of five redwood tanks 24 feet in diameter by 10 feet deep equipped with Dorr rake thickeners. Three 10- by 10-foot Dorr agitators are spaced between the thickeners, and the cyanide solution will run counter-current to the pulp. Tailing will be discharged from the last tank without filtering. Gold will be precipitated by the Merrill-Crowe process.

The mill is expected to process 250 tons of dump material in 24 hours which will yield 25 tons of minus 40-mesh product assaying from $15 to $25 in gold for the cyanide process. In October 1947 eleven men were employed filling and priming the cyanide leaching tanks. S. B. Dickey Jr. is mill superintendent.

Red Jacket group (Gaymon-Spaulding claims) includes six unpatented claims in sec. 24, T. 29 N., R. 11 E., M. D., owned by Frank Schmidig, Box 655, Susanville, California. Gold occurs in quartz veins and stringers in shear zones in quartz diorite. Most of the gold is found in pockets where the quartz is stained red and brown by limonite or sooty black by manganese. Some of the quartz contains small vugs lined with minute

quartz crystals. The claims have been prospected by numerous shallow cuts, pits, and short adits, many of which are now caved and inaccessible. Schmidig has about 4 tons of sorted quartz ore sacked at the portal of an adit on the Red Jacket claim where an open cut was driven S. 12° W. about 35 feet through quartz diorite to a face 12 feet high. At 25 feet from the entrance an adit was driven S. 75° E. for 24 feet. There is no well-defined wall, but narrow quartz stringers are plentiful. Schmidig was working alone in August 1947.

Miscellaneous Stone

Grayson and Spurgeon Cement and Gravel Company. Harold Grayson and Guy O. Spurgeon, 1512 Fourth Street, Susanville, operate a basalt rock quarry in sec. 7, T. 29 N., R. 11 E., M. D., on land leased from the Red River Lumber Company. The fine-grained dark-gray columnar basalt is drilled with jackhammers. Vertical holes spaced at 8-foot intervals are drilled 8 feet deep, loaded with 40 percent dynamite, and detonated electrically. The broken rock is pulled over a rail grizzly with 10-inch spaces by a 12-cubic foot slusher operated by a Construction Machine Company double-drum hoist driven by a 13-horsepower Allis-Chalmers gasoline engine. The undersize slides to a 10- by 20-inch jaw crusher set to crush the material to $1\frac{1}{2}$ inches. Power for the jaw crusher is obtained from a Cletrac 60 tractor with a power take off through a 12-inch belt that is 50 feet long between pulleys. The crushed rock slides to a double-decked 3- by 8-foot Cedar Rapids vibrating screen driven by a John Deere gasoline engine. The top-deck screen is $1\frac{1}{2}$-inch mesh, the bottom-deck screen $\frac{1}{16}$-inch mesh. The minus $1\frac{1}{2}$-inch and plus $\frac{1}{16}$-inch material slides to a 16-inch by 20-foot conveyor belt loader driven by an air-cooled Wisconsin single-cylinder gasoline engine, and is discharged into dump trucks. Minus $\frac{1}{16}$-inch material is discarded.

Equipment includes a Sullivan 350-cubic foot portable air compressor and three Dodge dump trucks. About 50 cubic yards of crushed rock is produced in a 6-hour shift. Four men are employed at the plant and quarry, and two truck drivers haul the rock 8 miles to Susanville where it is used for concrete aggregate. Guy Spurgeon is in charge of the operation.

MENDOCINO COUNTY

Carbon Dioxide

Cal Dri Ice Corporation, 1168-70 Battery Street, San Francisco, California, is producing carbon dioxide from six wells located on the east bank of the Russian River about 2 miles north of Hopland. The wells are 8 to 10 inches in diameter and were drilled about 350 feet deep. Carbon dioxide and water rise in the well casings and are collected in a steel pipe 4 inches in diameter; they are discharged into a metal cylindrical tank fitted with a riser pipe 12 inches in diameter, in which the gas is separated from the water. Water is discharged from the tank by a float valve. The dry gas is drawn through a welded steel pipe 4 inches in diameter by vacuum pumps and collected in a gasometer tank. The carbon-dioxide gas is compressed in a two-stage compressor to 550 pounds per square inch and cooled in three ammonia condensers to a liquid. Moisture is removed between the first and second condensers by passing the gas through four steel tanks filled with calcium chloride crystals. Two tanks between the second and third ammonia condensers are filled with carbon and other reagents to purify the gas. Methane is removed in a gas separator follow-

ing the third ammonia condenser. The liquid carbon dioxide is stored in a receiver under 550 pounds per square inch pressure and has a temperature of minus 40° centrigrade. It changes to "snow" when it is released into a chamber in which the pressure drops to 135 pounds per square inch. The snow is pressed into ice cakes in a hydraulic press under a pressure of 2,000 pounds per square inch. The cakes are 10- by 10- by 12-inches and weigh 60 pounds each. About 240 cakes are made in three shifts. They are double-wrapped in paper bags and stored in an insulated room, or loaded directly into refrigerator trucks for delivery to Sacramento, San Jose, Redding, or Stockton. The company operates four refrigerator trucks having a capacity of 190 blocks each. Some ice blocks are sawed into slabs an inch thick for special purposes. Henry De Lotty, general manager, has an office in Ukiah. Robert Hollander is superintendent at Hopland, and six men are employed in three shifts.

Gibson carbon-dioxide wells are located on the south side of Clay Street west of Eastlick Street in Ukiah. They are owned by L. J. Gibson and Bess Gibson, his wife. No. 1 well is 10 inches in diameter at the bottom and 235 feet deep. The first 75 feet was drilled through clay and gravel, and the remaining 160 feet was in hard gray rock. The well has casing through 75 feet, and the gas is shut in. No. 2 well has 250 feet of casing 12 inches in diameter and was drilled through 390 feet of hard gray rock to a depth of 465 feet. The well flowed gas and water at first but it is now being pumped. The carbon-dioxide gas is separated from the accompanying water and compressed to 1,200 pounds per square inch pressure in a three-stage compressor. The gas is dried by passing it through calcium chloride dryers, purified by passing it through tanks filled with carbon and other reagents, and cooled to a liquid in a series of ammonia condensers. The liquid carbon dioxide is pumped into insulated tank trucks for delivery. No dry ice is manufactured. The plant is operated by three men working three shifts, and a fourth man is employed as a relief man. Mr. L. J. Gibson is in charge of the plant.

Coal

Flood Estate. E. J. Thorpe of Stockton, Ben Neuman of Santa Rosa, and associates, have built about a mile of access road to a coal deposit on the north side of the Eel River in sec. 2, T. 21 N., R. 13 W., M. D. The road leaves the Dos Rios-Covello highway at a point about $6\frac{1}{2}$ miles east of Dos Rios. The property was last operated in 1941 by the Ocean Coal Company. It was deeded back to the Flood Estate, owners of the mineral rights, by a quitclaim deed dated June 30, 1942. The coal is developed by an adit driven N. 57° W. 75 feet from the portal, thence N. 12° E. 27 feet, and thence S. 75° E. 50 feet to the face. The adit is about 10 feet wide and timbered. A few of the caps are broken but the coal seems to stand firm with little slacking. For the first 50 feet in the adit the coal strikes N. 60° W. and dips 34° NE., but at the face it strikes S. 75° E. and dips 80° SW., suggesting a synclinal fold with the trough sloping toward the river. The footwall is a firm, fine-grained gray shale. In some places the bed is 12 feet wide, and no hanging wall is exposed. The bed seems to be solid black, shiny coal. The Eel River coal has been classified as a very good grade of sub-bituminous coal. The hanging wall exposed in the cut above the adit shows sandstone and shale next to the coal, and from 5 to 10 feet of brown soil. The sandstone is burned red

and some of the hanging-wall rocks are partly fused where they are exposed in the open cut. A fine-grained greenish-gray igneous rock outcrops about 300 feet southeast of the portal of the adit. It stands about 250 feet higher than the sedimentary rocks on its north and west sides and strikes S. 65° E. Many large boulders on the south and west sides have broken from the igneous outcrop.

Lee Giersch and Guy Creason of Dos Rios are building the access road and will mine the coal by stripping it with bulldozers and mining with a power shovel. Their equipment includes a Lima power shovel with a three-quarters cubic yard bucket; two TD-8 International bulldozers, and an International 11-cubic yard Mississippi wagon. Three men were working with the partners when the property was visited December 16, 1947.

Thomas (Carbon Company) coal mine, situated in SE$\frac{1}{4}$ sec. 13; E$\frac{1}{2}$ sec. 24; N$\frac{1}{2}$ SW$\frac{1}{4}$ NW$\frac{1}{4}$ and E$\frac{1}{2}$ sec. 25, T. 21 N., R. 13 W., M. D., is owned by Mrs. T. F. Hudson of Fresno, California, Mrs. Hazel Boyd Hunter, William Corbaley Hunter, and Robert Boyd Hunter, all of 1713 Santa Clara Avenue, Alameda, California; J. R. Thomas, Lilburn Gibson, H. O. Cleland, Mrs. H. O. Cleland, and W. P. Thomas of Ukiah, California, and Mrs. O. G. Steen of 38 West Poplar Street, San Mateo, California. On April 14, 1944, a contract to sell this mine was given to Ben Neuman, 619 King Street, Santa Rosa, California. Neuman has also secured a right-of-way from owners of land along the south bank of Middle Fork of Eel River for bridges, roads, railroads, tramways, etc., to the coal deposits. He prospected the outcrops with a bulldozer in 1946.

Development includes surface cuts; a 450-foot shaft inclined 15° E.; and some 500 feet of drifts on the vein. The vein is 12 feet thick, strikes N. 45° W. and dips 20-30° NE. It contains a good grade of subbituminous coal with a low ash content.[4]

Miscellaneous Stone

Ukiah Gravel and Cement Company, John Freitas, owner, Box 187, Ukiah, is producing sand and gravel from a bar in the Russian River about a mile east of Ukiah. The gravel is dug to water level about 12 feet below the surface with a Unit Power shovel equipped with a $\frac{5}{8}$-cubic yard bucket and powered with a Waukesha engine. It is loaded into two White and one Mack 5-cubic yard dump trucks, and hauled to the crushing and screening plant. Material over 1$\frac{1}{4}$ inches is crushed in a Symons 2-foot cone crusher to minus 1$\frac{1}{4}$ inches and delivered to a trommel screen above a four-compartment wooden storage bin by a rubber belt conveyor 16 inches wide, and 90 feet long between pulleys. Four sizes of material, from 1$\frac{1}{4}$ inches to minus $\frac{1}{4}$-inch, are produced. About 40 percent of the material screened is minus $\frac{1}{4}$-inch. Trucks can be loaded directly from the four storage compartments. The sand and gravel can be diverted from the conveyor belt before it discharges into the trommel and dropped onto a 16-inch belt conveyor about 50 feet long and sent to the steel Guntert and Zimmerman Transmix plant. This plant has four steel compartments holding 40 cubic yards of material each—two for sand, one for $\frac{3}{4}$-inch, and one for 1$\frac{1}{4}$-inch sizes. A steel cement silo 9 feet in diameter holds 300 barrels of bulk cement. It is loaded by a bucket elevator and a screw conveyor. All materials can be weighed out

[4] Laizure, C. McK., Mendocino County: California Min. Bur. Rept. 19, pp. 150-154, 1923.

of the mixer according to determined specifications. Electricity for operating this plant is generated by a Westinghouse 156 kilovolt-ampere generator driven by a Caterpillar D-13,000 diesel engine through a V-belt drive. The generator is also coupled to a Sterling diesel 70-horsepower engine. It was formerly driven by two Sterling diesel engines. Equipment includes a Wilson-Hornet 300-ampere welder, a South Bend lathe and a Buffalo drill press, two 4¼-cubic yard capacity Tex transit mixers, a D-8 Caterpillar tractor with a bulldozer blade, a 14-cubic yard Carryall, and a Buckeye Model-12 ditch-trencher.

The capacity of the plant is about 500 cubic yards of sand and gravel per day. Three men are employed in addition to the owner and his two sons. Most of the material is used as aggregate in building and highway construction.

MODOC COUNTY

Gold

Blue Bell group of three claims in sec. 1, T. 47 N., R. 15 E., M. D., is owned by William R. Larkin of Alturas. Two adits were driven in rhyolite. One is 40 feet long in a S. 55° E. direction; the other, 40 feet lower in elevation, is caved at the portal. Larkin said that he shipped 6 tons of quartz float that assayed $403 in gold from this claim in 1934-35 and that 400 pounds of vuggy quartz float assayed $9000 per ton. He has been trenching the slope between the two adits with a bulldozer, searching for the source of the rich float.

Klondyke group of 12 claims, located in the High Grade district of Modoc County in secs. 1, 12, T. 47 N., R. 15 E., M. D., is owned by Mrs. W. D. Broaddus and Archie Polite of Fort Bidwell, California. It is leased to Ed Benefiel of New Pine Creek, Oregon. No development work has been done on these claims since World War II, but Benefiel and his wife have been building a 25-ton milling plant to treat about 1,500 tons of ore stockpiled on mine dumps. Trucks will dump the ore into a 5-ton crude-ore bin from which it will be fed into a 9- by 12-inch Blake jaw crusher, crushed to ½-inch and dropped into a 25-ton fine-ore bin. A horizontal shaking plate feeder will feed a set of 9- by 18-inch rolls set to crush to ⅛-inch. The crushed ore will be dropped into a wooden scrubber trough 6 inches wide, 12 inches deep, and 16 feet long. A chain with paddles made of belting will drag the coarse sands along the scrubber trough and discharge them into a set of 5- by 16-inch finishing rolls. The overflow from the scrubber trough will flow to a 16-mesh circular screen 30 inches in diameter. The screen oversize will be returned to the scrubber trough by a drag chain and belt conveyor and then returned to the finishing rolls. The undersize from the finishing rolls will go to the screen. The undersize from the screen will flow to an overflow plate amalgamator of Benefiel's design. The sands from the amalgamator will be treated in a cylindrical mercury trap which is 3 feet in diameter and has four 4- by 6-inch traps. They will then be treated in a rocker concentrator 28 inches wide by 36 inches long, having 5 compartments with five 1½-inch pipe plugs. The overflow will go to an 80-mesh wheel-screen classifier 30 inches in diameter and 24 inches wide. The minus 80 mesh product will be discharged to tailing and the plus 80 mesh material will be returned to the scrubber trough by the chain-drag conveyor. Power will be furnished by a six-cylinder Paige automobile engine. The property was visited July 17, 1947.

Moonlight group includes the Moonlight, Paradise, Sunbeam, and Bald Eagle quartz claims in sec. 6, T. 47 N., R. 16 E., M. D., owned by Wellman M. Smith, Box 224, Lakeview, Oregon. On the Moonlight claim, which is a relocation of the Gold Shore Lode, a shear zone in rhyolite strikes northward. Gold occurs in a rhyolite breccia composed of pink, red, tan, white, and gray angular fragments of rhyolite which have been cemented together by silica from hot solutions which also deposited gold, some pyrite, and arsenopyrite.

At an elevation of about 7,200 feet, an open cut 6 feet wide by 8 feet deep has been dug in a S. 30° E. direction for 66 feet. Smith said that assays of the wall rocks average $13 in gold. At the end of the cut, a shaft has been sunk for a total depth of 23 feet on a vertical fault fissure. About 2 inches of bluish-green talc with soft brown clay seams including quartz and rhyolite fragments is frozen on the east wall. The soft brown earthy portion of the vein along the east wall ranges from 4 to 18 inches in width and assays up to $1,700 in gold. A shipment of 5,473 pounds of this material in November 1946 yielded a net of $1,495.17. Three feet of the hard rhyolite breccia below this soft brown earthy high-grade material assays $39 per ton in gold.

An old adit 60 feet lower in elevation was driven about 410 feet in southerly and westerly directions, and a survey may show that it has reached a point where the extension of the fault fissure would cross it.

Equipment includes a Sullivan 210-cubic foot portable compressor; a Cochise jackhammer with drill steel and jack bits; 1,500 feet of mine rails; two mine cars; several hundred feet of 2-inch steel pipe, and accessory small mining tools. Smith has been working alone, timbering the old adit where needed and sacking the high-grade ore from his shaft for shipment. In September 1947 the property was purchased by J. H. Causten of Nevada.

Perlite

Evening Star claim includes 40 acres in the NW¼ NE¼ sec. 22, T. 46 N., R. 14 E., M. D., owned by Jean Haney and Mary Weisman. It is leased to the National Perlite Company of Campbell, California. A timber bunker of 25 tons capacity was built at the highway. A second bunker some 400 feet higher and 600 feet southeast was loaded by pushing the perlite into a bunker with a bulldozer. A single-bucket tramline having a 30-cubic foot bucket suspended from two 8-inch pulleys traveled on a 1-inch steel wire rope, and carried the perlite from the upper to the lower bunker. It was operated by a single drum hoist by means of a chain and sprocket drive from a four-cylinder Dodge engine. The brake drum is 20 inches in diameter and 2 inches wide. The perlite has a pearly to glassy luster, and is dark to light gray. It is fragmental, and few pieces exceed 4 inches in size. There are some bands of reddish agglomerate, which turn white on roasting. Shallow pits and test holes at irregular intervals indicate that the perlite may occur over all of the 40 acres. Ollie Simonson and an associate mined about 125 tons of perlite from this claim in 1947. It was shipped by truck to Campbell, California. The property has been idle since May 1947.

Pumice and Volcanic Ash

Boorman Pumice Products Company, a partnership composed of Clarence, Earl, Leonard, and Irvine Boorman is addressed at P. O. Box

624, Klamath Falls, Oregon. The company has located association placer claims covering 680 acres including the NE¼ SW¼, the SE¼, and the SW¼ NE¼ sec. 25, T. 44 N., R. 4 E.; SW¼ sec. 19, T. 44 N., R. 5 E.; and a 5-acre mill site at the railroad in sec. 19, T. 44 N., R. 6 E., M. D.

At the pit in the NE¼ sec. 25, T. 44 N., R. 4 E., M. D., the pumice is about 4 feet deep above brown volcanic cinders. It is white to gray in color and has an average maximum size of about an inch. There are occasional lumps of lava and obsidian. Dump trucks holding about 8 cubic yards are loaded by a Barber-Green loader driven by a Buda gasoline engine. There are twenty-four 20- by 11- by 10-inch buckets with a maximum lift of 18 feet and a capacity of 1 cubic yard each per minute. The pumice is pushed to the loader with a Cletrac bulldozer. At a second pit, trucks are loaded by pushing the pumice with a bulldozer over a trap through a 4-inch log grizzly into a truck. In 1947 some trucks were loaded with a 3-cubic yard Carryall pulled by a Caterpillar tractor. The pumice is hauled over fair roads about 8 miles to the Great Northern railroad at Tionesta.

At the mill site at Tionesta, the trucks are driven up a timber ramp 16 feet wide, 70 feet long, and 12 feet high. The pumice is dumped from the trucks directly into railroad cars. A second ramp is built of railroad tie cribbing and is dirt filled. Trucks driven up this ramp dump the pumice into a 15-cubic yard hopper, and it is drawn onto a 14-inch rubber belt conveyor, 24 feet long between pulleys. The conveyor feeds a set of 20-inch rolls with 12-inch faces. The crushed pumice drops into an elevator boot from which it is lifted 26 feet by a chain and sprocket bucket elevator. The elevator discharges onto a 14-inch conveyor belt 12 feet long, which drops the pumice through a slide into a 14-inch swinging pipe for loading railroad cars. Power is supplied through belts and pulleys by a Holt four-cylinder gasoline engine.

Irvine Boorman was working alone in July 1947 mining the pumice at the pits, crushing it and loading the cars at Tionesta. The hauling is done by contract at a cost of 70 cents per cubic yard of raw pumice. Trucks can make eight trips in an 8-hour shift. Three cars of raw pumice, and one car of crushed pumice were shipped per week. The Great Northern Railroad freight rate is 8½ cents per hundred pounds for shipment to the Boorman Pumice Products Company plant at Klamath Falls, Oregon.

Foster volcanic sand pit is located on patented land in the SW¼ NE¼, the SE¼ SW¼, and the SE¼ sec. 14, T. 43 N., R. 13 E., M. D. It is owned by L. E. Foster, Star Route, Alturas. The sand is loaded into a truck through a timber trap with dirt-filled ramps on each side. It is hauled to the trap by a Fresno scraper pulled by a pair of horses. About 5,000 cubic yards of sand per year is mined and used for bedding stock cars. A small amount has been shipped to be used for sand in the manufacture of pumice building blocks.

Glass Mountain Brick Company, Box 10, Star Route, Tulelake, California, is a partnership composed of Martin Hyytinen, Nillo Hyytinen, Harry L. Holmquist, B. C. Stewart, and Roy T. Burns. They have located a 5-acre mill site in the SW¼ SE¼ sec. 24, T. 44 N., R. 6 E., M. D., and have built a plant to manufacture building blocks from pumice aggregate. A rock- and dirt-filled ramp permits trucks to dump into a wooden hopper 10 by 10 feet square on top, and built wedge-shape to an 8-foot

depth. The hopper is lined with corrugated sheet iron and slopes to a 6- by 18-inch slot discharging on an 18-inch by 16-foot belt conveyor. The conveyor feeds a set of 12- by 20-inch rolls driven by a 10-horsepower electric motor. The rolls are set flush, under spring tension so that the pumice is crushed to a maximum $\frac{3}{8}$-inch size. The crushed pumice is dropped into an elevator boot and lifted 28 feet by a bucket elevator having fifty 6- by 5- by 5-inch buckets on a 6-inch belt. The elevator discharges into a fine-ore bin 14 by 14 feet square on top and pyramid shaped with a 10-foot depth.

The pumice is drawn through a gate over an 18-inch bar grizzly with openings spaced at $2\frac{1}{2}$-inches. The undersize slides into a Stephen Flam concrete mixer 36 inches in diameter and 4 feet long in which a steel shaft fitted with six paddles is rotated by a 5-horsepower single-phase electric motor. Power is supplied by the California-Oregon Power Company. A 10-horsepower three-phase motor will be used when the necessary transformer can be obtained. The mixed aggregate is drawn through a chute to a flat metal sheet from which it is hoed into a Model-4 Stephen Flam brick machine operated by a $1\frac{1}{2}$-horsepower electric motor. Forms are available to manufacture six blocks 4 by 6 by 12 inches, or three blocks 8 by 8 by 16 inches. The bricks from the machines will be loaded on a four-wheeled rubber-tired truck and hauled to drying stacks. Water for the operation is hauled in a tank truck from Perez and pumped into a metal cylindrical tank of 650 gallons capacity. It is then piped to the mixer. The partners were working alone when the plant was visited in July 1947. The crushed aggregate will be purchased from operators in the Glass Mountain area and the blocks will be delivered by truck.

Glass Mountain Pumice Company is owned by C. V. Enloe Jr., of Dorris, California. Pumice is purchased from the Pumice No. 2 pit owned by Roy Nial Fouch Jr., and hauled in trucks about 8 miles to the plant, situated on the Great Northern Railway siding at Ainshea Butte. The trucks are driven up a dirt ramp to discharge the pumice through a rail grizzly with 3-inch openings into a wooden bin 10 feet wide by 15 feet long and 10 feet deep. The pumice is drawn from the bin into a sprocket and chain bucket-elevator, raised 16 feet, and discharged into a set of 18-inch by 16-inch rolls. It is crushed to $\frac{1}{4}$-inch maximum size. Power is supplied by a Chrysler "Industrial" six-cylinder engine. The crushed pumice is dropped on a 14-inch conveyor belt 35 feet long, which discharges into railroad cars. Power for the conveyor belt is supplied by a single-cylinder Wisconsin air-cooled engine. The plant was idle when visited in July 1947.

Glass Mountain Volcolite Company plant at Tionesta is owned by H. W. Free. Pumice is dumped from trucks onto a platform or shoveled directly into a hammer mill equipped with 22 hammers revolving 2,000 revolutions per minute. In the rainy season, a set of 10- by 16-inch rolls are substituted for the hammer mill. The minus $\frac{1}{4}$-inch product is dropped into a bucket elevator which discharges it 16 feet above the ground into a 60-cubic yard bin. The pumice can be loaded into trucks or drawn onto steel-sheeted platforms at the side of batch mixers inside the building. For manufacturing building blocks, ground pumice is shoveled into mixers and cement is added in the ratio of one shovelful of cement to nine of the pumice aggregate. Water is added to give the desired consistency.

A, BASALT ROCK COMPANY QUARRY
Preston Island, Del Norte County

B, CONCRETE BATCH PLANT
Ukiah Gravel and Cement Company, Mendocino County

C, CARRICO AND GAUTIER OPERATION
At Shasta Iron Company mine, Shasta County

3—92259

A, LINCOLN GOLD COMPANY DREDGE
On Clear Creek, Shasta County

B, OAKS SAND, GRAVEL, AND CEMENT PRODUCTS COMPANY
Crushing and screening plant, Shasta County

A, PUMICE PIT
On Volcolite placer claim, Modoc County

B, MILL
At Middle Fork mines, Siskiyou County

A, MIRES AND UNDERSETH DREDGE
Coffee Creek, Trinity County

B, THOMPSON DIVIDE MINING COMPANY DREDGE NO. 2
Trinity River, Trinity County

Batches are mixed in a Century bread-dough mixer 2 feet in diameter and 30 inches long, and in a steel cylinder 2 feet in diameter and 3 feet long, in which a steel shaft fitted with 10 steel paddles is rotated by a 3-horsepower electric motor at 65 revolutions per minute. The mixed batches are discharged onto steel plates and are hoed into the vibrating block machines. Two block machines are installed at this plant, one at the side of each mixer. The machines were built at the plant and they can be fitted with forms to produce bricks or blocks in a variety of sizes and shapes. The plant has a capacity of about 2,000 units in 8 hours.

Miers and Renstrom, a partnership composed of Charles Allen Miers and George A. Renstrom of Tionesta, are mining pumice from the Raino claim in sec. 29, T. 44 N., R. 5 E., M.D., held by Lorraine Renstrom. The pumice at this pit is about 30 inches deep above brown volcanic cinders. It is loaded into trucks with a Baughman loader having a pan-belt conveyor 14 inches wide by 10 feet long. The pumice is shoveled onto the conveyor which feeds a bucket-elevator equipped with 27 buckets 10 by 6 by 4 inches. It is raised about 10 feet and loaded into trucks. Power is supplied by a Briggs & Stratton single-cylinder 4-horsepower gasoline engine. At the Miers millsite in Tionesta, the pumice is dumped on a stockpile or into a 10- by 10-foot pyramid-shaped hopper of 10 cubic yards capacity. It is drawn from the hopper onto a 14-inch belt conveyor 35 feet long between pulleys. The belt discharges into a set of rolls 10 inches in diameter by 20 inches wide, driven by a six-cylinder Waukesha engine.

The pumice is crushed to minus $\frac{3}{8}$-inch size and dropped onto a 14-inch conveyor belt 25 feet long, which discharges it into railroad cars. The conveyor is operated by a Wagner 1-horsepower electric motor. A building 36 feet wide by 50 feet long built of pumice blocks is located at this millsite. It has walls 10 feet high and a corrugated sheet iron roof, and houses a Flam block machine and a conical-mixer of 3-cubic feet capacity. The crushed pumice aggregate is hand shoveled into the mixer, which is driven by a $\frac{1}{4}$-horsepower electric motor. The mixed batches are discharged onto a flat metal plate from which they are hoed into the vibrating block machine. Both 4- by 4- by 12-inch and 6- by 8- by 12-inch blocks can be made. The block machine was idle when visited in July 1947.

Thompson and Benedetti Plant. Paul Thompson and Alvin Benedetti, Tionesta, California, mine pumice from the Pumice No. 2 pit in the SW$\frac{1}{4}$ sec. 26, T. 44 N., R. 4 E., M.D., owned by Roy Nial Fouch Jr. Trucks are loaded by a Caterpillar tractor equipped with a front-end hydraulically operated bucket of half a cubic yard capacity. At Tionesta, the trucks are backed up a dirt-filled ramp and the pumice is dumped through a grizzly built of 6- by 12-inch timbers spaced 4 inches apart into a wooden bunker 13 by 13 feet square on top and having a capacity of 30 cubic yards. The pumice is drawn from the bunker to an 18-inch conveyor belt 35 feet long between 12-inch pulleys. The belt discharges through an eccentric feeder into the top pair of a double set of 14- by 30-inch rolls spaced at $\frac{1}{4}$-inch. The crushed product of the top rolls feed a second pair of rolls set against a spring tension to deliver a minus $\frac{1}{4}$-inch product. Power is supplied through belts from a Continental six-cylinder gasoline engine. The crushed pumice is discharged from the rolls onto a belt conveyor 18 inches wide and 40 feet long, which is driven

by a $2\frac{1}{2}$-horsepower single-cylinder Wisconsin gasoline engine. Either railroad cars or trucks can be loaded from this conveyor. Thompson and Benedetti work alone and deliver either the crushed or crude pumice as ordered.

Timber Mountain Pumice Products Company, Timber Mountain, California, Perry Hawkins, Tionesta, California, owner, moved from the Glass Mountain Volcolite Company plant at Tionesta in October 1946. Operation of the plant at Timber Mountain started May 30, 1947. Crushed pumice aggregate with a maximum size of $\frac{1}{4}$-inch is purchased from operators in the Glass Mountain area. In July 1947, Thompson and Benedetti were delivering the crushed pumice from the Pumice No. 1 claim owned by Roy Fouch at a cost of \$2.50 per cubic yard. Hawkins said that about 100 blocks could be made from a cubic yard of aggregate using a mixture of one part cement to nine of aggregate.

Trucks are backed up a ramp built of 6- by 12-inch timbers and the pumice is dumped on a 16- by 32-foot floor. It is shoveled into a 5-cubic foot hopper, from which it can be discharged into a mixer 4 feet in diameter by 3 feet long driven by a Star automobile engine through a rear axle assembly. The mixed aggregate is discharged onto a metal plate from which it is hoed into a Western Sales Company electric vibrating mold operated by a 1-horsepower electric motor. Magnesium-metal pallets are used at this plant instead of the ordinary plywood variety. They cost 52 cents each. Water is hauled from Perez in a tank truck having a capacity of 700 gallons. Two men were employed in July 1947 and the capacity of the plant was about a thousand 6- by 8- by 12-inch blocks per shift.

Volcolite association placer claim includes 160 acres in the SW$\frac{1}{4}$ sec. 30, T. 44 N., R. 5 E., M. D., owned by H. W. Free of Tionesta and associates. It is leased on a royalty basis to C. C. Jeskey and his son James C. Jeskey of Tionesta. The pumice is about 30 inches deep above brown volcanic cinders at this pit. Trucks are loaded with a Wagner Scoopmobile equipped with a bucket of $\frac{3}{4}$-cubic yard capacity. The pumice is hauled to the Glass Mountain Pumice Producers mill site at the railroad in Tionesta in sec. 19, T. 44 N., R. 6 E., M. D., where it is dumped on a stockpile or unloaded by shoveling into a wooden hopper above a steel shaker-conveyor. The conveyor feeds a pair of rolls 18 by 20 inches which crush the pumice to a maximum size of a quarter of an inch. The crushed material is elevated by a bucket elevator equipped with 46 buckets 4 by 4 by 6 inches, and discharged into a metal hopper. Railroad cars or trucks are loaded from the hopper by means of a sheet-iron pipe 12 inches in diameter. Power is supplied by an eight-cylinder Rickenbacker automobile engine. The Jeskeys work alone. They started operations here December 15, 1946.

SHASTA COUNTY

Asbestos

Stock asbestos property includes 1,023 acres of patented land in secs. 1, 2, 3, 4, T. 37 N., R. 5 W.; secs. 33, 34, T. 38 N., R. 5 W., and 17 unpatented claims containing approximately 340 acres in T. 37 N., R. 5 W., M. D. It is owned by the heirs of the Sarah I. Stock estate. Ida M. Beyle, Bellflower, California, one of the heirs, is agent for the estate. The

property is leased to Homer E. Fenn, 133 Katherine Street, Salinas, California. Amphibole asbestos occurs in small lenses and pockets in peridotite. It is mined by drilling holes about 8 feet deep with a jackhammer where asbestos shows in the formation, blasting lightly and sorting, cobbing, and sacking the asbestos by hand. The No. 1 grade is sold for use in acid filters and (including 30 percent moisture) sells for $250 per ton, f. o. b. cars at Dunsmuir. The No. 2 grade sells for $55 per ton at the highway. Crysotile asbestos outcrops in serpentine over an extensive area in sec. 33, T. 38 N., R. 5 W., M. D., and a road is being built to develop and mine it. A small milling plant consisting of a No. 2 Williams pulverizer driven by a Waukesha four-cylinder engine, cyclone blowers, and screens for separating various size fibers has not been used in recent years. Mining equipment includes a Hewitt Machinery Company portable compressor, a Model "A" Ford with a Smith compressor-head, a Chicago-Pneumatic jackhammer with $\frac{7}{8}$-inch hexagonal drill-steel, Timken bits, and a half-ton four-wheel-drive Dodge pickup-truck.

Sylvester Asbestos. Ray J. Sylvester, Box 1435, Weed, California, is mining amphibole asbestos from a deposit in the NW$\frac{1}{4}$ sec. 1, T. 37 N., R. 5 W., M. D., which he has leased from the Southern Pacific Land Company. An adit was driven N. 25° W. about 45 feet through a blocky, greenish-black peridotite. It is timbered with 10- by 10-inch square timbers and lagged with split lagging. A small amount of amphibole asbestos shows on the right side of the adit about 10 feet from the portal. This adit is now used for a store-room and shop. A second adit whose portal is about 12 feet to the west has been driven in an average N. 30° W. direction for 88 feet through blocky, greenish-black peridotite. At about 35 feet from the portal, a lens of asbestos was cut and followed for about 40 feet in the drift. The lens was about 30 inches wide for much of its length and tapered to about 8 inches near the face. The asbestos occurred in a vertical fissure and the best fiber was found in the center. A maximum of 6 inches of hard greenish asbestos called "bone" was on each wall. The fibers were horizontal and pointed in the direction of the drift. The walls beyond the hard greenish fiber are hard greenish-black blocky peridotite. The material is mined by drilling the hard black rock with a mounted jackhammer and Timken bits, loading with 40 percent gelatin, and blasting. The fibrous material was sacked without sorting in the mine and hauled to the camp, where it was spread on a wooden table for sorting. One ton of selected material was shipped to Baltimore, Maryland, for a sample. Equipment includes a Sullivan portable compressor, a single-drum hoist mounted on 10- by 10-inch timber skids and driven by a Buick automobile engine, a mine car, two jackhammers, drill steel, and hand tools. About 60 tons of unsorted mine-run asbestos fiber is stored in sacks at the camp. Two men were employed September 15, 1947.

Copper-Zinc

Afterthought mine at Ingot, 23 miles northeast of Redding, was reopened in 1945 by the Coronado Copper and Zinc Company, a Harvey Mudd subsidiary with offices at 1206 Pacific Mutual Building, Los Angeles. A crew of 20 men under Lyttleton Price, superintendent, and Jack Widauf, foreman, reopened the mine, which had been closed for about 19 years, and the property was mapped and sampled. Exploration by diamond drilling disclosed the existence of zinc-copper ore bodies in

the shales near the contact with rhyolite. Subsequent drifting developed an ore body 240 feet long and 10 feet wide on the 400-foot adit-level. On the 100-foot level, an ore body 200 feet long, 40 feet wide, and 150 feet high was developed. The ore averages 20 percent zinc, 2.4 percent copper, 4 percent lead, 9 ounces of silver, and $2 in gold. Studies on methods of beneficiating the ore have indicated that very satisfactory recoveries can be made.

In June 1947 the Coronado Copper and Zinc Company purchased the property from the California Zinc Company for a reported $110,000. A bridge is being built from the highway across Little Cow Creek and a mill is being designed to treat 125 to 150 tons per day. Development work has been suspended until the milling plant is completed. Former operations at the Afterthought mine are described in earlier reports by Logan [5] and Tucker.[6]

Mountain Copper Company, Ltd., L. T. Kett, general manager, J. G. Huseby, assistant general manager, 216 Pine Street, San Francisco 4, California, is mining about 700 tons of pyrite per day at their Hornet mine on Iron Mountain in sec. 35, T. 33 N., R. 6 W., M. D. The "Hornet" ore body is a kidney-shaped massive pyrite deposit in alaskite porphyry. It is about 1,500 feet long in a northeasterly direction, 600 feet in maximum width, and up to 200 feet thick. The Richmond haulage level runs westward for about 800 feet to the massive pyrite ore body and continues S. 45° W. about 1700 feet. The haulage adit runs beneath the ore body and steep incline-raises are run up to and through the pyrite at 120- to 150-foot intervals for manways and ore passes. The ore body is divided into 60- by 150-foot blocks and mined by a room and pillar system. Scram drifts are run beneath the blocks of ore in each direction from the ore passes, and short ore passes 4 by 4 feet in section are run on a 50° to 60° slope about 20 feet high to the stope floors. Pillars about 15 feet wide are left between ore passes. The stopes are mined about 30 feet wide and 20 feet high. The ore is drilled with stoper drills, from staging when necessary, and is blasted by 40 percent dynamite with fuse and caps. The broken ore slides down the short ore passes to the scram drifts and is pulled to raises from the haulage level by scrapers. Raises are run in the stope pillars to the top of the ore and a coyote drift is driven above the top of the stope. Pockets are cut at intervals to hold 30 to 40 boxes of 40 percent bag powder and the ore remaining in the roof of the stopes is blasted down. The pillars are robbed by drilling them with diamond drills and blasting. The ore breaks well, and little secondary blasting is necessary. It is loaded into cars of 10-ton capacity on the haulage level, and five or six cars are pulled by a trolley locomotive manned by a crew of three. The pyrite is crushed to minus $\frac{3}{8}$-inch size and shipped to chemical plants in San Francisco bay area.

The "Mattie" ore body was discovered in the Richmond adit, and diamond-drill prospecting indicated an ore body of about 180,000 tons assaying 2.25 percent copper and 3.5 to 4 percent zinc. The zinc-copper ore body occurred as a fringe on the hanging wall of the massive pyrite deposit. It was about 1,000 feet long, 120 feet wide, and 40 feet thick. It was mined first by sub-level stopes and diamond-drill blast holes and

[5] Logan, C. A., Shasta County: California Min. Bur. Rept. 22, pp. 143, 211-213, 1926.

[6] Tucker, W. B., Shasta County: California Min. Bur. Rept. 18, pp. 595-598, 1922.

later by a longwall room and pillar system; drilling was done with percussion air drills. Laboratory studies indicated that a satisfactory separation of the copper and zinc minerals could be made. As both copper and zinc were in great demand for the war effort, and incentive premiums were offered for them, a 350-ton selective flotation plant was built near the portal of the Richmond adit and put into operation in 1943. The ore was crushed to minus three-eighths of an inch in gyratory crushers and rolls, and then 80 percent was ground to minus 325 mesh, and 95 percent to minus 200 mesh in ball mills. Lime was added to the ball mill feed along with zinc sulphate and sodium cyanide to depress the iron and zinc in the Fagergren cells. Varying amounts of Z-3, Z-5, and B-23 reagents were used to suit the feed. The copper concentrates recovered assayed about 13.7 percent copper. A recovery of 88.5 percent copper was being made in June 1944. The tailing from the copper cells was treated with copper sulphate, lime, B-23, Aerofloat 15, and Reagent 637, in amounts to suit the pulp, and sent to a bank of ten 56-inch Fagergren rougher cells. The zinc pulp temperature was kept above 80° fahrenheit by steam from a 75-horsepower boiler. The concentrate from the first five cells went to two cleaner cells whose concentrate in turn was treated in two recleaner cells. The concentrate from the recleaner cells was thickened and filtered for shipment to the smelter. The tailing from the first five cells was treated with additional Z-3 and sent to the second group of five rougher cells. The tailing from the second group of cells was sent to a storage pond and the concentrate was reconditioned and returned to the flotation circuit. A minimum of 47 percent zinc in the concentrate was required by the smelter. Concentrate assayed 54.65 percent zinc in June 1944 and a recovery of 54.4 percent was being made. The copper concentrate was shipped to Tacoma, and zinc concentrate to Great Falls for recovery of the metals.

It was learned that the fluctuation in the mill heads was due not only to variations in the relative amounts of copper, zinc, and iron, but also to the length of time the ore was broken and exposed to the air. Changes in reagents had to be made to meet the varying conditions. The zinc-iron ratio in the concentrates was constant, so a rapid method of determining the amount of zinc was to run an iron assay and multiply by a constant.

Mining and milling of zinc-copper ores were suspended June 30, 1947. A diamond drill exploration program to develop additional copper-zinc ore bodies is being carried forward on two shifts on the Okash claim in Slide Rock Canyon about 2 miles southwest of the Hornet mine.

The Mountain Copper Company, Ltd., has a remarkable history of operation in Shasta County. It is described in an article by William F. Kett, former general manager, who retired in 1946 after more than 41 years of service.[7] C. W. McClung is superintendent in charge of operations at Iron Mountain, R. K. McCallum, mill superintendent, and R. P. Bagley, mine foreman. One hundred and twenty men are employed on two shifts.

Gold

Auclair Suction Dredge. E. Auclair is operating a small suction dredge on his placer claim on Clear Creek in sec. 12, T. 32 N., R. 7 W.,

[7] Kett, W. F., Fifty years of operation by the Mountain Copper Company, Ltd., in Shasta County, California: California Jour. Mines and Geology, vol. 43, pp. 105-162, 1947.

M. D. The pump, engine, and sluice box are mounted on a wooden hull 5 feet wide, 9 feet long, and 10 inches deep. The plunger pump is 11 inches in diameter, has an 18-inch stroke, and is driven by a 3-horsepower single-cylinder air-cooled engine. Operation consists of first building small dams and diverting the water from a strip of gravel along the creek, and then removing the top gravel to within about 3 feet of the bedrock with a small bulldozer. Sands are then pumped up through a 3½-inch suction hose and discharged into a sluice box 11 inches wide by 8 feet long, fitted with steel reinforcing rods half an inch in diameter, spaced half an inch apart, and laid longitudinally over a 5-mesh wire screen placed above cocoa matting. The suction hose can be moved around the boulders over the bedrock, and the bedrock can be watched through a glass-bottom viewing box. Auclair works alone except for occasional help. He has been working the claim since March 1947. The dredge has a capacity of 1 to 3 cubic yards of sand per hour.

Hammer placer mine includes three patented claims on Clear Creek near Oak Bottom in sec. 7, T. 32 N., R. 6 W., M. D. It is owned by J. J. Hammer of Schilling and leased and operated by A. R. Potts of Schilling. The property is mined with a small suction dredge consisting of a wooden barge on which a suction pump 24 inches in diameter, and a sluice box 2 feet wide and 16 feet long is mounted. The pump is driven by a Ford Model "A" engine. A trench about 15 feet wide is dug to within 3 feet of bedrock with an International TB-40 bulldozer. The remaining sand and gravel is then pumped through a hose 4 inches in diameter and discharged into the sluice box. An undercurrent 3 feet wide fitted with metal lath over corduroy cloth is used to recover the fine gold. The sand concentrate is treated further in a Denver gold pan. Potts had one man employed on April 10, 1947.

Lincoln Gold Dredging Company, a partnership composed of E. M. (Bing) Clark of Redding and Walter Jansen of Lincoln, California, owns the mineral rights on four placer claims on Clear Creek in sec. 34, T. 33 N., R. 7 W., M. D. They have designed and built a new type of washing plant for a dragline-dredge operation that leaves the tailing piles practically level and with the sand on top. This is accomplished by using a horizontal trommel in which the gravel is moved by a spiral screw conveyor to be discharged into the dredge pond about 10 feet beyond the stern of the barge. The sand is collected in sumps on each side of the trommel after going through the sluice boxes, and hydraulic elevators throw it out and over the top of the tailing piles. There is no belt-stacker.

The washing plant is built on six steel pontoons making a hull of 40 by 36 feet. The dragline bucket discharges the gravel into a heavy steel hopper 10 by 11 feet on top, and water is sprayed over it from three sides. There is no grizzly above the hopper, and the gravel slides down a chute 42 inches wide into the trommel. The trommel is 64 inches in diameter and 40 feet long and has a 20-foot length of screen. It is set horizontally and is fitted inside with a spiral conveyor 8 inches high, which has a pitch of 52 inches. The gravel is discharged from the trommel 10 feet beyond the stern. The trommel is driven by a 40-horsepower Westinghouse motor through a chain drive and rotates 11 revolutions per minute. A steel distributing trough 30 inches wide and 6 inches deep extends longitudinally beneath the trommel. A water pipe 6 inches in diameter with spray vents spaced at 12-inch intervals is set beneath the

center of the trommel and provides wash water for the gravel. Along each side of the trough, pipes 4 inches in diameter direct additional water into the trommel through spray vents at 8-inch intervals. The sand can be washed from the trough and collected in a 4-inch pipe at the stern end.

The sand is run over eight-side sluice boxes 32 inches wide by 10 feet long and discharged through an undercurrent into a down-stream sluice on each side of the trommel. The sluice boxes are fitted with expanded metal over cocoa matting. Amalgamating plates 12 inches wide by 30 inches long are set at the head of each side sluice beneath the expanded metal. The sand flows into sumps at the end of the downstream sluice boxes and is ejected back over the gravel tailing by hydraulic elevators. Water for the elevators is supplied by a Byron-Jackson two-stage 6-inch centrifugal pump driven by a 14-horsepower General Electric motor. The wash water for the hopper and trommel is supplied by a Byron-Jackson 12-inch centrifugal pump driven by a 30-horsepower General Electric motor. Electric power is supplied by a Caterpillar D-13,000 diesel engine driving a self-regulating alternating-current generator.

Equipment includes a Northwest dragline with a 50-foot boom and a bucket of $1\frac{1}{2}$ cubic yards capacity; power is furnished by a Caterpillar D-13,000 diesel engine. The gravel is about 10 feet deep above a slate bedrock. About 2,500 cubic yards are dug in three shifts with 11 men. E. M. Clark, one of the owners, is in charge of the operation.

N. R. A. (Highland Lake) mine includes five unpatented claims in sec. 12, T. 37 N., R. 6 W., M. D., owned by Philip Munko, Box 151, Castella, California. Gold is found in black, flaky, serpentine; in a soft, talcy white to gray alteration product of serpentine; and in shear-zones in peridotite. There are also areas in which free gold can be panned from the reddish-brown soil. The gold is free and it was probably deposited from solutions circulating in the sheared and crushed serpentine. Boulders of serpentine that have been almost entirely replaced by silica are found in the shear zones, but no quartz veins or seams were noted.

These claims have been prospected since 1889, and many shafts, adits, and trenches have been dug in search of a vein or ledge. One single-compartment shaft sunk on a 43° slope in a S. 27° W. direction is 132 feet deep and has short crosscuts north and south at 70 feet. A small ball mill with amalgamation plates and a shaking table were installed at this shaft at one time. The mill building has fallen down and the shaft is now full of water. Munko has one man employed with a bulldozer cutting prospect trenches in the shear zones. Specimens of serpentine including green and blue copper minerals have been taken from two cuts on this property.

Sunshine Gold Mining Company owns 530 acres of patented land 3 miles north of Shasta in sec. 15, T. 32 N., R. 6 W., M. D., including the Sunshine mine and other quartz prospects formerly held by location. The company is incorporated in Nevada, and 300,000 shares of one dollar par value have been issued. The shares are closely held. Elmer C. Brain, P. O. Box 555, Redding, is president and general manager; W. Davis McDuffie, vice-president; and O. C. Wright, secretary-treasurer. The old Sunshine vein was developed by an adit driven N. 3° W. 100 feet to the vein. The vein was about 5 feet wide, strikes S. 85° E., and dips 63° S. The footwall is quartz diorite and it has many veinlets of quartz which

carry gold for 2 feet beneath the vein. The hanging wall is meta-andesite. A drift 65 feet long on the Sunshine vein is caved for about 35 feet and has been abandoned. A concrete dam was built near the mouth of the adit to make a water reservoir of the old workings. A new adit is being driven from a point farther west and must be driven 60 feet to reach the vein. A quartz vein 10 inches wide in the new adit strikes N. 70° E. and dips 73° S. The footwall is quartz diorite and the hanging wall is meta-andesite. The property will be mined by open cuts with a drag-scraper pulled by a double-drum hoist driven by a Chevrolet automobile engine. The ore will be dumped into a raise from the adit, drawn into mine cars from a chute, and trammed to the mill.

The mill is situated below the adit, and mine cars are dumped over a bar grizzly spaced at 6 inches. The oversize is crushed in a 6- by 16-inch Joshua Hendy jaw crusher belt-driven by a Buick automobile engine. The undersize drops to a fine-ore bin of 100-ton capacity. The ore is crushed to 100-mesh in a 5- by 5-foot Denver Engineering Company ball mill, belt-driven by a 110-horsepower International diesel engine. The crushed ore is fed to two amalgamation barrels 20 inches in diameter by 4 feet long, where 50 to 60 percent of the gold is recovered. The tailing is delivered to a Dorr double-rake classifier which returns the sand to the ball mill and delivers the slime to a Grouch Engineering Company flotation machine. The mill will have a capacity of about 4 tons per hour. Five men are employed getting the property ready to operate.

Thurman Gold Dredging Company, C. H. Thurman, president and general manager, 235 Montgomery Street, San Francisco 4, California, is operating a bucket-line dredge on Clear Creek about 2 miles west of Highway 99. The company owns 720½ acres of grounds in secs. 26, 27, T. 31 N., R. 5 W., M. D. Digging started December 1, 1940. The Yuba-built dredge is built on 33 steel pontoons making a hull 50 by 112 by 8 feet. The digging ladder has 69 buckets of 9 cubic feet capacity and is capable of digging 35 feet below water level. The buckets are pulled by two 100-horsepower synchronized electric motors. The trommel is 7 feet in diameter and 33 feet long and has 28 feet of $\frac{7}{16}$- to $\frac{5}{8}$-inch holes. It is rotated by a 40-horsepower electric motor. The stacker belt is 36 inches wide and 100 feet long and it is driven by a 20-horsepower motor. The swing winch is driven by a 40-horsepower motor. The high-pressure pump is driven by a 75-horsepower motor and the low-pressure pump by a 40-horsepower motor. Gold is recovered in sluice boxes fitted with Hungarian riffles. The gravel is about 23 feet deep above a soft volcanic ash and clay bedrock. The dredge is digging about 400 cubic yards per hour. The recovery is said to be checking the sampling, which was done with churn drill holes 6 inches in diameter drilled with a Keystone drill at 150-foot intervals. The crew averages 19 to 20 men. W. J. Harvey, superintendent, is in charge of the operation.

Iron

Shasta Iron Company, Robert B. Finn, president, 384 Second Street, San Francisco, California, owns 205 acres of patented mining claims about 12 miles north of Redding near the Junction of the Pit and McCloud Rivers in sec. 26, T. 34 N., R. 4 W., M. D. Irregular lenses of magnetite occur along a line trending northeastward between marble or limestone and quartz diorite. In places a green basic intrusive rock lies between

the magnetite and the quartz diorite. The magnetite is associated with garnet, epidote, pyroxene, serpentine, and sometimes pyrite and chalcopyrite. In the spring of 1942, Lee Carrico and Melvin Gautier, general contractors, 365 Ocean Avenue, San Francisco, leased the property and built roads to the deposit. The high-grade magnetite was mined and shipped to west coast ship-building plants, where it was used as a heavy aggregate in concrete to ballast naval vessels, and for blocks to anchor naval mines. The lenses were mined by stripping the overburden from the ore bodies with bulldozers and power shovels, drilling vertical holes in the ore about 16 feet deep with jackhammers, blasting, and loading dump trucks with power shovels. The trucks were ferried across Shasta Lake on barges operated by the U. S. Bureau of Reclamation and driven down U. S. Highway 99 about 12 miles to the Hein Brothers gravel plant in Redding, where the iron ore was washed and screened before shipment by rail to west coast shipyards. Production was at a rate of about 10,000 tons per month during the war, and from 10 to 25 men were employed at the pits.

In 1944 a geologic map and dip-needle survey made by Carl A. Lamey, geologist for the U. S. Geological Survey, and five diamond drill holes totaling 2,890 feet drilled under the supervision of John R. Shattuck for the U. S. Bureau of Mines, furnished data from which it was estimated reserves totaled 4,680,000 tons of ore containing 37.82 percent iron, 13.24 percent silica, 0.17 percent sulphur, 0.014 percent phosphorous, and 0.273 percent manganese.[8]

The U. S. Bureau of Mines has installed a 6-ton Heroult electric arc furnace in a pilot plant at Shasta Dam. Special alloy steels are made from a sponge iron reduced from magnetite mined from the Shasta Iron Company deposit. Investigation of processes using electrolytic manganese and electrolytic chromium for making alloys instead of the customary ferro-manganese and ferrochromium is proceeding under the supervision of William W. Stephens, engineer in charge for the U. S. Bureau of Mines. Sample ingots and billets of the alloy steels will be tested in west coast manufacturing plants.

Miscellaneous Stone

J. H. Hein Company, Box 226, Redding, California, owns and operates a sand and gravel plant on the east bank of the Sacramento River on Highway 44 in sec. 6, T. 31 N., R. 4 W., M. D. Gravel is dug to a depth of about 8 feet below water level and loaded onto dump trucks of 3 cubic yards capacity with either a P & H shovel with a $\frac{1}{2}$-cubic yard bucket or a Speeder dragline with a 40-foot boom and a $\frac{3}{4}$-cubic yard bucket. The trucks dump into a wooden bin from a dirt-filled ramp. The gravel is drawn from the bin by a shaking feeder and dropped into a 15- by 38-inch Wheeling jaw crusher. The product from the jaw crusher drops on a belt conveyor 30 inches wide and 120 feet long between pulleys, and is discharged over a 3- by 8-foot Niagara double-deck vibrating screen fitted with 3-inch and $1\frac{1}{2}$-inch screens. The plus 3-inch material is run through a set of 22- by 40-inch rolls and is returned to the screen by the main conveyor belt. The undersize from the Niagara screen drops on a 3- by 8-foot Symons double-deck screen fitted with $\frac{3}{4}$- and $\frac{1}{4}$-inch screens. Hoppers are provided for various sizes of products, and the

[8] Lamey, C. A., Shasta and California iron-ore deposits, Shasta County, California: California Div. Mines Bull. 125, pt. K, pp. 139-164, 1946.

sizes can be changed as needed by changing the screens. The plant capacity is about 500 tons in 8 hours. Most of the material is sold for road building or maintenance.

The company also operates a hot-mix plant at which ½- or ¾-inch gravel is dumped from trucks into a hopper from a dirt-filled ramp. A bucket-elevator lifts the gravel from a boot below the hopper and discharges it into a 6- by 25-foot rotary drier. It is heated to 300-350° fahrenheit by an oil burner. The hot gravel is lifted to the top of the plant by a bucket-elevator and discharged on a 4- by 8-foot three-deck vibrating screen fitted with ¾-, ⅜-, and $\frac{3}{16}$-inch screens. Bins are provided for each of these sized products and they can be weighed into the batch hoppers to meet specifications. The gravel is mixed with 5 percent oil for 30 to 45 seconds in a pug mill of 1,500-pound capacity and discharged into dump trucks for delivery. The plant was mixing about 500 tons in 8 hours in October 1947. Five men were employed. E. J. Ferrell was foreman at the plant.

The J. H. Hein Company also owns a Butler concrete batching plant which it has leased to R. J. Kettlewell. The plant is of all-steel construction and has a 1,750 barrel cement silo and four sand and gravel bunkers. The sand and gravel are weighed, and the water is metered into the batch mixers according to specifications. Batches are loaded into transit-mix trucks, one of 3 cubic yards capacity and two of 4 cubic yards capacity each. The plant has a capacity of 200 cubic yards in 8 hours. Three men are employed.

Oaks Sand, Gravel, and Cement Products Company is owned and operated by Grover E. Oaks and his son Edward Oaks, 1737 Yuba Street, Redding. The plant is located on the north bank of Clear Creek just west of its junction with the Sacramento River in sec. 30, T. 31 N., R. 4 W., M. D. The gravel is dug 8 to 10 feet deep to water level with a Model M 6-cubic yard Carryall pulled by a D-6 Caterpillar tractor. It is hauled about 400 feet, dumped through a rail grizzly spaced at 6-inches into a 10- by 10- by 10-foot pyramid-shaped steel hopper. The gravel is drawn from the hopper by a Bodinson automatic feeder onto a 24-inch conveyor belt 180 feet long between pulleys, and discharged about 40 feet higher over a three-deck vibrating screen fitted with 2¼-, 1½-, and ¾-inch screens. Material over 1½-inches in size can be delivered to a storage bin or to a jaw crusher to be crushed to 1-inch maximum size. A second three-deck Pioneer vibrating screen is fitted with 1½-, ¾-, and ⅜-inch screens. By changing screens, material of any desired size can be obtained and delivered to separate bins. The storage bins are located above a tunnel and the desired size of material can be drawn off onto a conveyor belt 24 inches wide and 180 feet long and sent to the concrete batching plant. The batching plant is an all-steel structure with a four-compartment bin for the aggregate materials. All materials for batches are weighed and the water is measured to meet specifications. The batches are mixed in three Yaeger 3-cubic yard, and one Smith 2-cubic yard concrete mixers. Deliveries are made by four transit-mix trucks. The plant has a capacity of 185 cubic yards of concrete in 8 hours. Sand and gravel are loaded on trucks from the batching plant or from the storage bins by a Scoopmobile fitted with a ¾-cubic yard bucket. There are two Scoopmobiles and they can be fitted with concrete batch buckets which can lift and pour concrete into forms 20 feet high, or they can be fitted with forks to lift pallet loads of concrete blocks on or off trucks.

The concrete block plant is adjacent to the batching plant, and batches are drawn into a steel hopper suspended from a pillar crane and pushed by hand to be discharged into a rotary mixer of 1 cubic yard capacity. The mixed batch is discharged into a skip, hoisted about 15 feet, and discharged into a steel funnel-shaped hopper above a two-block Stearns ''Joltcrete'' machine. The concrete block plant has a capacity of 2,000 blocks in 8 hours. Deliveries are made within a radius of 85 miles. The plant employs 25 men. Edward Oaks superintends the operations.

SISKIYOU COUNTY

Gold

County mine (Siskiyou) includes five claims along the east side of Indian Creek in sec. 31, T. 18 N., R. 7 E., M. D., owned by the James L. Wortham estate, Los Angeles, California. It is leased and operated by Leonard Crumpton of Happy Camp. The gravel is 10 to 15 feet deep above a serpentine and granite bedrock. The overburden of red soil is 40 to 50 feet thick. Many boulders must be blasted and handled with a derrick. Water is supplied from Mill Creek through a ditch 1½-miles long. It is delivered through 900 feet of 18- and 20-inch welded steel pipe under 200 pounds pressure to a No. 2 giant fitted with a 5-inch nozzle. There are 300 feet of sluice boxes 24 inches wide and 3 feet deep fitted with rail riffles laid longitudinally. The gold is heavy, and no undercurrents are used. Boulders are handled by a derrick with a mast 60 feet high and a boom 60 feet long. Power is furnished to a double-drum hoist by a McCormick-Deering engine. Leonard Crumpton and his brother Victor operate the property with the part-time help of three men.

Donnelly placer includes 40 acres in sec. 7, T. 16 N., R. 8 E., H., on the west bank of the Klamath River. It is owned by C. E. Reagan of Happy Camp. A bench of gravel about 25 feet above the river is 300 feet wide, and the gravel is 14 to 60 feet deep above a greenstone bedrock. Water for a No. 2 giant is furnished by a Byron-Jackson 8-inch centrifugal pump driven by a six-cylinder Fageol gasoline engine coupled with a four-cylinder Waukesha gasoline engine. Wash water is supplied by a Worthington 12-inch centrifugal pump. There are 60 feet of 2- by 2½-foot sluice boxes fitted with block riffles. The property is operated by the owner and two men.

French Gulch Gold Dredging Company, 307 Russ Building, San Francisco 4, California, Etheredge Walker, president and general manager, is operating a bucket-line dredge on Indian Creek northwest of Fort Jones on land in secs. 13, 14, T. 44 N., R. 9 W., M. D., owned by George Milne of Fort Jones. The dredge was built on Clear Creek in Shasta County in August 1940 by the Washington Iron Works of Seattle. It was assembled in 28 days by 12 men of the dredging crew supplemented by a construction superintendent, electrician, and carpenter of the Washington Iron Works. The dredge was moved from Clear Creek to its present location in July 1946. It is built on 35 steel pontoons making a hull 90 by 40 by 7 feet. The 85-foot digging ladder carries 75 buckets of 4½-cubic feet capacity, and 32 buckets are discharged into the trommel per minute. They are pulled by a 100-horsepower motor. The trommel is 5 feet in diameter and has a 21-foot length of slotted screen with ⅜-, 1-, and 1½-inch holes. It is rotated by a 30-horsepower motor. There are eight transverse sluices 30 inches wide and 10 feet

long, feeding the downstream sluices on each side. They are fitted with rubber Hungarian riffles. A Bingham high-pressure 8-inch centrifugal pump is driven by a 75-horsepower motor. The 10-inch low-pressure pump has a 50-horsepower motor. The stacker belt is 30 inches wide and 85 feet long, and it is driven by a 15-horsepower motor. The gravel is about 18 feet deep above a soft serpentine bedrock. From 3,000 to 4,000 cubic yards of gravel are dug per day. Equipment includes a Bucyrus S-90 Carryall and a Caterpillar D-6 bulldozer. Ed Shuford is superintendent in charge of operations and 18 men are employed in three shifts.

General Placers Corporation, Horace J. Leavitt, president; O. Jack Boucher, secretary, is associated with the General Dredging Company of Natoma, California. It operates a dragline dredge on Middle Fork of Humbug Creek, a short distance above its mouth, in sec. 1, T. 45 N., R. 8 W., M. D. The Bodinson washing plant is built on six steel pontoons making a hull 40 by 30 feet and 3 feet deep. An additional pontoon 3 by 3 by 16 feet is placed beneath the stacker. The trommel is 54 inches in diameter by 30 feet long and has 20 feet of perforations. The stacker belt is 30 inches wide and 50 feet long. Water is supplied by a Byron-Jackson 10-inch centrifugal pump. Power is furnished by a Caterpillar D-13,000 diesel engine. There are nine cross sluices and two tail sluices on each side of the trommel, which contain boil boxes and are fitted with metal-lath riffles. The Model 8 Northwest dragline is equipped with a $1\frac{3}{4}$-cubic yard bucket. Equipment includes an Allis-Chalmers H.D.14C diesel bulldozer, a 1,500-watt electric light plant, Lincoln 400-ampere welder, and two acetylene welding outfits.

The corporation holds eight claims along Middle Fork and additional claims 6 miles up Humbug Creek from Middle Fork. The gravel is about 6 feet deep above a soft slate bedrock at the present location. It was tested by 4- by 4-foot shafts sunk at 150-foot intervals. A 12-man crew operates the dredge. Horace Leavitt is in charge.

Gold Ventures, Limited, Paul A. Bundy, president and general manager, Box 323, Grass Valley, California, has a lease with an option to purchase on the Portuguese placer in sec. 4, T. 46 N., R. 12 W., and sec. 32, T. 47 N., R. 12 W., M. D., owned by Stanley Davis of San Francisco, California. A dragline dredge operation was started July 21, 1947. Equipment includes a Lima dragline with a 70-foot boom and a 3-cubic yard bucket. Power is furnished by a Cummins 250-horsepower diesel engine. The Bodinson washing plant has five steel pontoons making a hull 36 by 48 feet and 54 inches deep. The trommel is 66 inches in diameter and 30 feet long with 20 feet of $\frac{1}{2}$-inch holes. The stacker belt is 30 inches wide and 60 feet long between pulleys. There are 12 side sluices 30 inches wide and two downstream sluices 30 inches wide on each side fitted with Hungarian riffles. Water is pumped by 10-inch and 4-inch United Iron Works centrifugal pumps. Power is supplied by a 200-horsepower Murphy diesel engine driving a 440-volt Acme electric generator. Each piece of equipment has a separate motor drive. There is an International T-D-18 bulldozer for clearing the land, and a Rowe 300-ampere arc-welder to make necessary repairs to steel equipment. About 10 feet of the barren top sand and gravel is stripped away with a bulldozer. The gravel is 18 feet deep above a hard bedrock. Jack Creeden is dredgemaster, and 11 men are employed.

Jumbo mine, consisting of 11 unpatented quartz claims, two placer claims, and a mill site in sec. 36, T. 40 N., R. 11 W., M. D., has been sold by Guy Ford of Weed, California to an association of which Fred Cook of Los Angeles is president; other principals include B. E. Patrick, Floyd Rexford, and J. C. Lyons. In the summer of 1947 a road was built to the property and machinery and equipment for a milling plant was moved to the site. The old caved adits have not been reopened. It is planned to mine by an open pit. A right to 250 miners inches of water brought to the property under 165-foot head through about a mile of ditch is included in the sale. Equipment at the property includes a Chicago-Pneumatic 315-cubic foot portable air compressor, two jackhammers, one 25-horsepower and one 15-horsepower Fairbanks-Morse hot-head engine, a Caterpillar D-4,600 diesel engine direct-connected to a 30 kilowatt generator, an 8- by 16-inch Wheeling jaw crusher, a Cottrell Engineering Company double-deck vibrating screen, a White ricochet pulverizer having four 8- by 8-inch blades revolving at 3,400 revolutions per minute, a Cottrell double-compartment pulsating jig, two Cottrell mullers 4 feet in diameter equipped with three shoes, a Cottrell amalgamator 4 feet in diameter with an inside copper band 10 inches high and six blades fitted with 10- by 12-inch rubber pads, two Cottrell 6-inch diameter screw-type dewaterers, and a 4- by 8-foot Cottrell concentrating table. It was not yet determined to what mesh the ore would be crushed. On October 8, 1947 a wooden building had been constructed to house the diesel engine and generator and some of the milling equipment. Mr. B. E. Patrick and one man were working at the plant.

K. C. mine includes 10 mining claims, one of which is patented in sec. 6, T. 45 N., R. 9 W., M. D., and all of sec. 1, T. 45 N., R. 10 W., except Lot 1, owned by Florence M. Cooper, Yreka. It is leased with an option to purchase by A. L. Damon, president of the Thompson Divide Mining Company. A quartz vein 8 to 48 inches wide strikes S. 30° to 70° W., and dips 18° to 33° N. The quartz is stained brown and is in bands from $1\frac{1}{2}$ to 4 inches wide separated by thin layers of black shale and light-brown clay seams. The property is developed by five adits from 80 to 400 feet long, three of which are caved and inaccessible; by short raises, and by open cuts on the vein. A new mill building has been built at the camp site with lumber sawed on the property. Dump trucks will haul the ore $1\frac{1}{4}$ miles down-hill to the mill and discharge it over a rail grizzly with $\frac{3}{4}$-inch spaces. The undersize will fall into the fine-ore bin. Oversize will be crushed to $\frac{1}{2}$-inch by a 6- by 8-inch jaw-crusher, and discharged into the fine-ore bin. The fine-ore bin has two chutes from which the ore will be drawn by disc feeders to feed a two- and a five-stamp battery. The stamps weigh 1,250 pounds and will drop 6 inches, 100 times per minute. The ore will be crushed to minus 40-mesh and the gold recovered by amalgamation on copper plates. The tailing will be concentrated on a Wilfley table. Mill-capacity is expected to be 25 tons in 24 hours. Water is obtained by gravity from a spring and delivered through 1,000 feet of 2-inch pipe to a galvanized tank of 1,200-gallon capacity. Power will be obtained from a diesel engine. There are five cabins including a boarding house at the camp. A cook and seven men were employed May 28, 1947. Tom Clark is superintendent.

Liberty Gold Dredging Company (Midland), Arthur C. Crawford, Sawyers Bar, president; R. C. Mollison, 1517 Rice Street, Vallejo, vice-president; and Jake Steffan, Sawyers Bar, secretary-treasurer; is remodeling a dredge on the North Fork Salmon River about 1½ miles west of Sawyers Bar. Four claims are leased from Ed Currens. The washing plant is built on four wooden pontoons, 10 by 30 by 3½ feet. The trommel is 4 feet in diameter by 30 feet long and has 23 feet of ⅜- to ½-inch perforations. Water is supplied by two 5-inch and one 10-inch Worthington centrifugal pumps. The stacker belt is 28 inches wide and 45 feet long between pulleys. Three cross sluices and three downstream sluices are on one side, and six cross sluices and two downstream sluices are on the other side of the trommel. The sluices are 48 inches wide and are fitted with expanded metal over cocoa matting. Power is furnished through a line shaft driven by a Fairbanks-Morse 85-horsepower diesel engine. Crawford uses a single dipper-bucket 6 feet wide by 10 feet long on the end of a steel channel slide instead of using a dragline. The dipper-bucket is operated by wire ropes from sheaves suspended from tubular steel masts which rise 35 feet above the deck. The dipper is lowered between two steel pontoons and pulled forward and upward by the ropes for digging. Power is supplied by a 30-ton reduction-geared winch. The channel slide-end moves up and down along the two steel guides and is steadied by counter weights. It is raised and lowered by a 5-ton haulback winch. When the dipper is raised, the sand and gravel slide into the trommel of the washing plant. Power is supplied by an 85-horsepower Atlas diesel engine. The dipper can dig a maximum of 30 feet below water level. It is mounted on two 8½- by 34-foot steel pontoons, and has a 6-foot 8-inch by 9-foot pontoon on the stern end connecting with the washing plant. A suction pump may be used to clean the bedrock. Gravel is about 18 feet deep above a hard slate bedrock. There are many medium-sized boulders. Crawford expects to employ seven men for a three-shift operation.

Long Gulch mine, in sec. 8, T. 45 N., R. 7 W., M. D., includes the Gold Leaf, Beauty, and Prairie claims owned by Paul and Harry C. Dobyns, 227 Pine Street, Yreka, California. It is leased with an option to purchase by a co-partnership composed of G. Ankeney, H. F. Lintner, E. L. McNaughton, and A. N. Whealdon. A quartz vein averaging about 3 feet in width has been developed by three adits. The lowest adit is about 450 feet long, 350 feet of which is a drift on a vein 2 to 3½ feet wide striking S. 35° to 72° W. and dipping 45° to 67° NW. About 160 feet from the portal, a raise 40 feet high on the vein holed to surface; and at 430 feet a second raise was run to connect with an adit 70 feet above. It holed into the adit about 20 feet from the face. The vein averaged 30 inches in width in the raise. A second adit, 70 feet higher, has a drift 176 feet on the vein, and a third adit about 300 feet higher has a drift 55 feet long on the vein and a raise 40 feet high to the surface. The ore from the uppermost adit was milled in an 8-foot arrastre in 1914, but recovery is not known. Recent mill tests show that very little free gold is in the ore. The vein is composed of white quartz with fine, sharp, pyrite cubes and occasionally some galena. Both walls are greenstone with thin seams of quartz parallel to the vein. Small pyrite cubes are plentiful. The vein has been faulted to the south for a maximum of 16 feet in three places. The faults strike S. 70° to 80° W. and dip 22° to 30° S. Equipment includes a small compressor, a mounted rock drill, drill steel, mine cars and acces-

sory small tools. Two men are drifting and raising on the vein to block out sufficient ore to justify building a small milling plant.

Middle Fork Mines. A. O. Witte of Redding has a lease with an option to purchase on two quartz claims owned by Everett Crouch, and four adjoining quartz claims on the Middle Fork of Humbug Creek in sec. 11, T. 45 N., R. 8 W., M. D., owned by Lowell Hall. Quartz stringers and narrow veins on these claims occur in a soft, medium-grained granodiorite near a contact with a fine-grained hornblende diorite. The quartz stringers have been crushed and brecciated. They are stained yellow and brown by limonite, and some are stained black by manganese. The Hall claims have been prospected by numerous shallow pits and short adits. An adit on the Crouch claims is 120 feet long, and there is an 80-foot vertical raise to the surface. The vein is 12 to 36 inches wide between granodiorite walls. An old trestle from the adit and a small mill building housing a 3- by 4-foot ball mill are in a wrecked condition.

Witte has built a small mill on the Hall claims. The ore is dumped over a steel-rod grizzly spaced at 1 inch into a hopper 30 inches square on top. The undersize drops through 12 feet of steel pipe 12 inches in diameter to a 5- by 7-foot fine-ore bin 8 feet deep. The ore is fed by a disc feeder to a Huntington mill 5 feet in diameter and 30 inches deep. It is ground to pass through 35-mesh screens. The crushed ore is run through a five-pan cascade-type amalgamator with 20-inch square pans fitted with 5- by 20-inch copper plates. The tailing is run through 20 feet of sluice boxes 10 inches wide and 2½ inches deep lined with corduroy. Power is supplied by a DeSoto automobile engine. One man is employed.

Quartz Hill mine includes about 75 acres of patented land at Scott Bar in sec. 16, T. 45 N., R. 10 W., M. D., under contract to Harry M. Thompson and associates of Seiad Valley. The mine is being developed for an open-cut operation by drilling holes 12 feet deep at 12-foot intervals from benches and moving the blasted rock with a power shovel and a bulldozer. Very rich ore was uncovered with a bulldozer in July 1947. Native gold and gold telluride are found in fine-grained gray brecciated Abrams schist containing coarse cubes of pyrite, some of which are coated with gold and gray petzite. Calcite cements the breccia. The ore occurs between walls of Abrams schist, which strike eastward and dip northward into the hill. It is in the footwall west of the Holmes fault, which strikes N. 45° E. and dips 50° SE. Thompson believes that the Holmes fault is pre-mineral. Quartz veins and rich gold ore have been found in the adjoining Scott Bar mine above the Holmes fault however. Tests were made to determine what average value could be expected if the whole hill were mined and milled. Material mined for samples was run through a small milling plant consisting of a size 50 Kue-Ken Balanced Crusher driven by a 25-horsepower motor. The crushed ore was delivered to a fine-ore bin by an 18-inch belt conveyor about 30 feet long. The fine ore was crushed by ten 850-pound Pacific Iron Works stamps driven by a 15-horsepower motor. The free gold was recovered on two 4- by 12-foot copper amalgamating plates.

The recovery was encouraging, and a 1,000-ton mill was put in operation January 12, 1948. The ore is mined in an open cut by using an Allis-Chalmers H.B. 10 bulldozer to push it to a hopper. A 3- by 8-foot apron feeder conveys the ore from the hopper to a Western Austin Com-

pany 38- by 24-inch jaw crusher driven by a 75-horsepower motor and set to crush to 4-inch maximum size. The minus 4-inch material is delivered to a 30-inch by 88-foot conveyor belt, which is suspended above the pit on wire rope cables, and dropped on a stockpile 45 feet below. A timbered opening beneath the stockpile has a chute mouth with a steel arc gate from which the ore is drawn to a belt conveyor 24 inches wide and 100 feet long and delivered to an 18- by 24-inch Kue-Ken balanced crusher driven by a 25-horsepower motor. The crushed ore drops on a single-deck Selectro vibrating screen driven by a 5-horsepower motor. Material over 16 mesh is delivered to a set of 40- by 22-inch rolls driven by a 50-horsepower motor. The product from the rolls is delivered to a second single-deck 3- by 8-foot vibrating screen driven by a 5-horsepower motor. Material over 16 mesh is delivered to a second set of 40- by 22-inch rolls driven by a 50-horsepower motor. The oversize is lifted about 3 feet by a hydraulic elevator and delivered to a 30-inch by 60-foot sluice box fitted with expanded metal lath over cocoa matting. Concentrate is saved and the tailing is run to waste. The minus 16 mesh material that went through the vibrating screens is delivered by launders to three 4- by 8-foot amalgamation plates followed by 4 by 4 feet of expanded metal lath over cocoa matting. The gold amalgam will be retorted and the concentrate will be shipped to the smelter. Twelve men are employed in the mine and mill. It is estimated that 1,000 tons can be mined and processed in 24 hours with a crew of 15 men. Harry M. Thompson supervises the operation.

Salmon River Mines Company [9] *(Trail Creek mine),* E. C. Latchem, Callahan, president and general manager, owns seven claims in sec. 12, T. 39 N., R. 10 W., M. D. A road is being built from Grizzly Creek to the mine and a 50-ton Marcy ball mill and six flotation cells have been purchased for a milling plant. Six men are building a road to the property with a Caterpilar ''60'' bulldozer. About $1\frac{1}{2}$ miles of road remained to be built in September 1947.

Scandia No. 1 [10] *dredge,* owned by Larsen Bros. and Harms Bros., Route 4, Box 2220, Sacramento is operating on Horse Creek in sec 7, T. 46 N., R. 10 W., M. D. They own the mineral rights on a strip of land a quarter of a mile wide and 4 miles long on Horse Creek from its junction with the Klamath River. Dredging was first started in December 1938. The top soil was stripped from the gravel before dredging, the tailing leveled after dredging, and the top soil was restored on this land.

Equipment includes a Marion 40-A dragline with a 60-foot boom and a 3-cubic yard bucket. Power is furnished by a Cummins 250-horsepower diesel engine. The Bodinson washing plant is built on eight steel pontoons making a hull 48 feet wide by 56 feet long. The trommel is 60 inches in diameter and 42 feet long with 30 feet of $\frac{5}{16}$- to $\frac{3}{4}$-inch holes. The stacker belt is 36 inches wide and 60 feet long. It is driven by a 15-horsepower General Electric motor. Water is pumped by a United Iron Works 10-inch centrifugal pump and a Rex Speed Prime 4-inch centrifugal pump. Power is furnished by a Caterpillar D-17,000 engine. Electric lights are supplied by a 1,500-watt Koehler light plant. There are

[9] Hamilton, Fletcher, Siskiyou County: California Min. Bur. Rept. 14, p. 841, 1914. Averill, C. V., Mines and mineral resources of Siskiyou County: California Div. Mines Rept. 31, pp. 307, 328, 1935.

[10] Averill, C. V., Dragline dredging in Siskiyou County: California Div. Mines Rept. 37, pp. 328-330, 1941.

12 cross sluice boxes 30 inches wide, and two downstream sluice boxes 30 inches wide on each side. They are fitted with Hungarian riffles. The gravel is 15 to 18 feet deep above a soft black schist bedrock. About 3,500 cubic yards are dug in three shifts. Cinnabar is recovered with the black sand, but it is not retorted.

The top soil is about 2 feet deep in section 7, and a 200-yard width is stripped with a LeTourneau 12-cubic yard Carryall pulled by a D-8 Caterpillar tractor. The tailing from the dredge is leveled with a D-8 Caterpillar bulldozer, and the soil is replaced evenly. Eleven men are employed. R. I. Barrett is dredgemaster.

Scott Bar Mines, Incorporated, includes 71.7 acres of patented land in secs. 16, 21, T. 45 N., R. 10 W., M. D., owned by George A. Milne of Fort Jones. It adjoins the Quartz Hill mine on the east and is in the same black micaceous schist, which includes many veins and lenses of white quartz. A white quartz vein 3 to 6 feet wide striking N. 89° W. and dipping 65° N. is developed by a 6- by 10-foot shaft 165 feet deep on an average 40° N. slope. On the 100-foot level the vein is 5 feet wide, strikes S. 89° W., and dips 65° N. A drift was run westward on it for about 50 feet. At the 155-foot level, the vein is more than 12 feet wide, and a drift was driven about 25 feet east. A rich pocket of gold was mined from this drift. The gold is associated with pyrite and galena and is often seen to form a thin coating on the pyrite. A fault at the bottom of the shaft strikes S. 85° E. and dips 40° S. A crosscut was driven north through the fault to cut 20 feet of white quartz with pyrite 253 to 273 feet north of the shaft. This quartz was discovered by a diamond drill hole driven north 40 feet from the crosscut at the 250-foot point. A drift was driven 160 feet eastward from the shaft in barren white quartz on the 165-foot level. A second diamond drill hole drilled 140 feet south of the end of this drift cut 8 feet of quartz, from 94 to 102 feet.

Equipment includes a single-drum hoist driven by a Dodge automobile engine, an Ingersoll-Rand 240-cubic foot air compressor, two Ingersoll-Rand jackhammer drills with shells and mountings, a supply of drill steel, and accessory small tools. The diamond drill equipment includes a Sullivan H.S.-15 core drill, 300 feet of drill rods, three model 7,100 A-C bevel drill-bits, an Ingersoll-Rand 315-cubic foot portable air compressor, and a Denver Gardner 3- by 2- by 3-inch duplex pump.

A small mill on the property includes a jaw crusher, Ellis ball mill Type B-1 with 40-mesh slotted screens, and a 2½- by 3-foot amalgamation plate. The crusher is driven by a 3-horsepower Fuller Johnson gasoline engine, and the ball mill is driven by a 3-horsepower John Deere gasoline engine. Four men are employed on development. George Milne and his son supervise the operations.

Yreka Gold Dredging Company, Etheredge Walker, president and general manager, 351 California Street, San Francisco, California, is operating a bucket-line dredge on the Klamath River near Seiad Valley. A detailed description of this dredge is given in earlier publications of the California Division of Mines.[11] When the dredge was moved to Seiad Valley in the summer of 1941 the digging ladder was extended 10 feet

[11] Averill, C. V., Gold dredging in Shasta, Siskiyou, and Trinity Counties: California Jour. Mines and Geology, vol. 34, pp. 123-125, 1938. . . . Placer mining for gold in California: California Div. Mines Bull. 135, pp. 300-303, 1946.

and the stacker 15 feet. A separate winch driven by a 40-horsepower motor was installed to raise and lower the digging ladder. In September 1947 the dredge was digging gravel 14 to 20 feet deep to a soft granite bedrock. A crew of 17 men are employed. Eric S. Peterson is dredgemaster.

Yreka Mining Company (Black Bear mine), E. A. Jackson, president, owns the Black Bear Consolidated quartz mine located 9 miles south of Sawyers Bar in secs. 7, 18, T. 39 N., R. 11 W., and sec. 13, T. 39 N., R. 12 W., M. D. In the summer of 1947, four men were employed running the old mine dumps through a small mill. The dump material, mostly black slate, was pulled to a wooden hopper by a 1-cubic yard drag scraper operated by a double-drum hoist driven by a chain and sprocket drive from a 20-horsepower four-cylinder Continental engine. Material remaining on a 3-inch spaced bar grizzly was discarded. An 18-inch belt conveyor about 20 feet long delivered the material from the hopper to a double-screen trommel 42 inches in diameter by 15 feet long. The material over $\frac{3}{16}$-inch was discarded to waste by a stacker belt 12 inches wide and about 15 feet long. The minus $\frac{3}{16}$-inch material was distributed to four Ace Centrifugal Separators, which are aluminum bowls 30 inches in diameter lined with concentric rubber riffles spaced about half an inch apart. Ore is fed to the bottom of the bowls through a vertical pipe $3\frac{1}{2}$-inches in diameter. The bowl is spun 132 revolutions per minute and the heavier particles are caught in the riffles while the lighter material overflows at the top to a launder, through which it flows to a Draper jig. Concentrate from the bowls is flushed out through the bottom. The jig concentrate is largely sulphide. Power is furnished by belts from a line shaft driven by a Budda 40-horsepower four-cylinder gasoline engine. The operation was shut down September 8, 1947 because of a shortage of water. E. M. Von Goerlitz was superintendent.

Yuba Consolidated Gold Fields (Siskiyou Unit), F. C. Van Deinse, general manager, 351 California Street, San Francisco, California, owns a strip of land about 4 miles long and 1,400 to 2,700 feet wide along the Scott River in secs. 6, 7, T. 40 N., R. 8 W.; sec. 1, T. 40 N., R. 9 W.; sec. 31, T. 41 N., R. 8 W.; and secs. 25, 36, T. 41 N., R. 9 W., M. D. Yuba No. 116 bucket-line dredge was built in sec. 7, T. 40 N., R. 8 W., in 1936. In June 1941 a Yuba bucket-idler was installed which made it possible to dig an additional 5 feet, to a maximum of 40 feet. On April 15, 1946 the dredge was shut down, and when operations were resumed on September 8, 1947, four additional pontoons had been added on each side to make a hull 64 by 144 feet. The digging-ladder was lengthened 18 feet 6 inches to a total of 111 feet 6 inches, and the stacker was lengthened 25 feet to a total of 150 feet. There are now 83 buckets of 9-cubic foot capacity driven by a V-belt from a 375-horsepower motor, and 22 to 24 buckets are discharged per minute. The 36-inch stacker belt is now driven by a V-belt from a 35-horsepower motor. The trommel is 8 feet in diameter and 48 feet long with 34 feet of $\frac{3}{8}$- to $\frac{5}{8}$-inch holes. It is revolved at 7 revolutions per minute by a 75-horsepower motor. The side sluice boxes are double banked and there are 3,500 square feet of riffle tables. The wooden riffles are shod with steel. A Byron-Jackson 12-inch centrifugal high-pressure pump is driven by a 100-horsepower motor, and a 12-inch centrifugal low-pressure pump is driven by a 50-horsepower electric motor. A 6-inch Byron-Jackson centrifugal pump driven

by a 40-horsepower motor is used to wash the gravel in the hopper and a 4-inch Byron-Jackson pump is used in the clean-up and for fire protection.

The dredge can dig to a maximum depth of 55 feet below water level. It is now digging 38 feet deep to a hard gray slate and some serpentine bedrock. About 400 cubic yards are dug per hour. The crew includes 17 men. W. B. Lewis, dredgemaster, is in charge.

Limestone

Electro Lime and Chemical Corporation, C. J. Montag, president; Dr. L. Underdahl, vice-president; P. M. Sherlund, treasurer; and G. R. Bethel, secretary; have offices at 536 Southeast 6th Avenue, Portland, Oregon. Limestone is mined from a deposit in secs. 4, 5, 8, T. 42 N., R. 6 W., M. D., owned by Sisto Mazzuchi of Gazelle. It is drilled by two men using jackhammers on wagon-drill mountings. Holes are spaced at 5-foot intervals, drilled 20 feet deep vertically, loaded with 40 percent dynamite, and blasted. The broken limestone is loaded onto dump trucks by a D-7 Caterpillar Scoopmobile fitted with a $2\frac{1}{2}$-cubic yard bucket, and hauled 3 miles to the crushing and screening plant at Gazelle. It is dumped into a 20-ton wooden bin from a ramp and fed into a 24- by 36-inch jawcrusher by a 30-inch Lipman feeder. The jawcrusher discharges minus 3-inch material onto a 24-inch conveyor belt 70 feet long, which delivers it to a 3- by 10-foot Pioneer double-deck vibrating screen driven by a $7\frac{1}{2}$-horsepower motor. Material over $1\frac{1}{2}$-inches and under $\frac{1}{2}$-inch is delivered to a Grundler 3XC-type hammer-mill driven by a V-belt from a 220-horsepower Hercules diesel engine. The $1\frac{1}{2}$- to $\frac{1}{2}$-inch material goes to a bin and is classed as carbide rock. The hammer-mill product is raised 28 feet with a bucket elevator to a 4- by 12-foot three-deck Seco vibrating screen fitted with 8-mesh screens. The oversize is stockpiled. The undersize is classed as agricultural limestone. It is weighed by an ''OK'' weighing machine into paper bags holding 100 pounds each, or loaded in bulk on cars or trucks for shipment. Material sold for agricultural limestone is specified as 100 percent minus 8-mesh, 50 percent minus 50-mesh, and 35 percent minus 100-mesh. It has a minimum of 95 percent $CaCO_3$ and a maximum of 1 percent $MgCO_3$. The plant was shipping 200 tons of agricultural limestone per day and 150 tons of carbide rock per week in September 1947. Four men were employed at the quarry and seven at the mill. C. E. Dingman, P. O. Box 44, Gazelle, is superintendent.

Pumice

Baker building blocks works is owned and operated by Clem Baker, Post Office Box 914, Yreka, California. Building blocks are made in a vibrating block machine either from volcanic cinders or pumice aggregate. The aggregate is hand shoveled from a stockpile into a set of 14-inch rolls driven by a 10-horsepower motor, and crushed to minus $\frac{1}{4}$-inch. The crushed material is raised by a bucket elevator and discharged into a 20-cubic yard bin, from which it is drawn into a $\frac{1}{3}$-cubic yard measuring hopper. Batches are mixed in the proportion of six parts aggregate to one part cement, and water is added to give the desired consistency. The vibrating block machine can make five blocks 6 by 6 by 12 inches or four blocks 6 by 8 by 12 inches at a time. Three men can make about 800 blocks in 8 hours.

The pumice is purchased from producers in the Glass Mountain area. Cinders are mined from a group of 12 claims on the foot of Cinder Cone Mountain about 8 miles north of Weed that are owned by Clem and Nettie Baker. The black volcanic cinder bed is at least 25 feet deep at the foot of the mountain. Very little material is over an inch in size. Trucks are backed up to the cinders and loaded by scooping the material into a slide to the trucks. The cinder pit is about 35 miles from the block plant at Yreka. Cinders are mined only as needed and no regular crew remains at the pit. From three to five men are employed at the Yreka plant.

Klamath pumice claim includes 20 acres in the SE¼ SW¼ sec. 26, T. 44 N., R. 4 E., M. D., owned by John Madsen, P. O. Box 711, Klamath Falls, Oregon. A road cut on this claim shows the pumice bed to be about 10 feet deep. No pumice is being mined, however, and only assessment work is being done. Madsen has a cabin on this claim and saws some scouring bricks from scoria boulders mined from four claims he owns in the Protection group located in the NW¼ sec. 35, T. 44 N., R. 4 E. He uses both a hand saw and a 24-inch emery wheel driven by a 6-horsepower gasoline engine to saw the scoria boulders into bricks 3 by 4 by 6 inches, and 4 by 4 by 6 inches in size, which sell for 25 to 35 cents each. Tim White is hauling scoria boulders to Klamath Falls, Oregon, from three other 20-acre claims of the Protection group which are owned by Charles P. Van Doren of Klamath Falls, Oregon. The dark-gray coarsely vesicular volcanic material mined from the top of Glass Mountain is called scoria by the miners.

Pumice No. 2 claim in the SW¼ sec. 26, T. 44 N., R. 4 E., and SE¼ sec. 27, T. 44 N., R. 4 E., M. D., is owned by Roy Nial Fouch Jr. of Tionesta. The pumice is 10 to 14 feet deep above dark-brown volcanic cinders. Trucks are loaded from a 30-cubic yard timber bunker which is filled by pulling a 1-cubic yard drag scraper over a grizzly on top of the bin. Power is supplied to a double-drum hoist by a six-cylinder Chevrolet engine through a chain and sprocket drive. Fouch works alone and sells the pumice at the pit. A portion of this claim is worked by Paul Thompson and Alvin Benedetti of Tionesta, who mine the pumice on a royalty basis. Their trucks are loaded with a Caterpillar tractor equipped with a front-end hydraulically operated bucket of half a cubic yard capacity. They have a crushing and loading plant at Tionesta and load trucks and railroad cars for delivery.

Miscellaneous Stone

Mount Shasta (Kottinger) gravel pit is located about 2 miles northwest of Mount Shasta in sec. 5, T. 40 N., R. 4 W., M. D., on ground owned by the McCloud River Railroad. The lease and equipment were purchased by J. S. Jensen and M. M. Thompson from A. E. Kottinger in August 1945. Andesitic gravel is dug to water level from pits about 25 feet deep. Equipment includes a P & H dragline with a 40-foot boom and a ¾-cubic yard bucket; a Byres ⅜-cubic yard shovel; and a portable bucket-line loader having 24 buckets 14 inches wide and 3 inches deep, chain driven from a Fordson tractor engine. The pit gravel is dumped from trucks through a rail-grizzly with 6-inch spaces into a hopper, and is fed into a jaw crusher set to crush at 2 inches. The minus 2-inch material is lifted

40 feet by a bucket elevator to discharge over a triple-decked vibrating screen fitted with 1-, ½-, and ¼-inch screens. Material over ½-inch in size includes 60 percent of the product and is classed as rock. Material passing through a ¼-inch screen is classed as sand. Gravel is made up of half sand and half rock. Material over 1-inch in size is crushed in a Telesmith gyratory crusher and discharged over the vibrating screen from a bucket elevator. Most of the material is sold for concrete aggregate. Three men are employed.

A. Young, South Highway 99, Yreka, loads sand and gravel from old dredge tailing piles on Greenhorn and Yreka Creeks and from an old creek bottom about half a mile east of Gazelle, which he has leased from F. Foulke of Gazelle. The gravel is loaded into dump trucks by power shovel and hauled to his Yreka plant where it is crushed and screened to the desired sizes for use either as concrete aggregate or for road construction.

TEHAMA COUNTY

Miscellaneous Stone

Baker Trucking Company, owned by H. V. Baker and A. A. Gebhardt of Hamilton City, operates a sand and gravel plant on the south bank of Thomes Creek about 2 miles east of Highway 99 W. The ground is leased from Elmer Clary, Richfield, California. Gravel is loaded onto 4-cubic yard steel dump trucks by an Osgood dragline with a 40-foot boom and a 1⅓-cubic yard bucket, or with a Wagner Scoopmobile with a ¾-cubic yard bucket. The trucks are backed up a dirt-filled ramp and emptied into a wooden hopper of 5 cubic yards capacity. A feeder belt draws the material from the hopper and discharges it over a steel-bar grizzly with 1-inch spaces. Oversize slides into a 36- by 12-inch Universal jaw crusher set to 1½-inches. The product from the jaw crusher and the undersize from the grizzly drop on a belt conveyor 18 inches wide by 100 feet long and are discharged over a 4- by 8-foot Cedar Rapids double-deck vibrating screen. Different mesh screens can be attached to the vibrating frames to give the desired sizes, and three separate bins are provided for the various sized products. Sand is washed in a sand washer and stored in a steel hopper of 21 cubic yards capacity. Oversize from the screen is conveyed by a chute to a set of 16- by 16-inch rolls which can be set to crush from 2½ to 7/16 inches. The crushed material is dropped on a conveyor belt 18 inches wide and 70 feet long and returned to the main conveyor belt, which discharges it on the shaking screen. The main products of the plant are 1½-, ¾-, and ¼-inch gravel and sand. About 200 cubic yards of sand and gravel are produced in 8 hours. Six truck drivers and a shovel operator were employed November 3, 1947. D. Palermo was in charge at the plant.

Draper and Adams, 315 Walnut Street, Red Bluff, are operating a commercial sand and gravel plant on the east bank of the Sacramento River a short distance north of U. S. Highway 99 E. The river gravel is pushed into a pile with an R.D.-8 Caterpillar bulldozer, and then pulled into a hopper with a 1-cubic yard V-type drag scraper. The scraper is operated by a double-drum hoist driven by a 50-horsepower electric motor through a V-belt. It is pulled by 300 feet of 1¼-inch wire rope and the haulback rope is ¾-inch in diameter and 700 feet long. A Pitman feeder with a 6-inch stroke feeds a conveyor belt 30 inches wide and 78 feet long,

which discharges the gravel over a 3- by 8-foot Niagra vibrating screen fitted with a $1\frac{1}{2}$-inch screen. Oversize slides to a 12- by 24-inch Cedar Rapids jaw crusher. The undersize from both the screen and the crusher slide to a 30-inch belt conveyor 208 feet long that rises 4 inches per foot, and is discharged on a 4- by 10-foot Niagara vibrating screen. The gravel is washed on the first 4 feet of the screen by a water spray. The screen delivers the $1\frac{1}{2}$-, $\frac{3}{4}$-, $\frac{3}{8}$-, and minus $\frac{1}{4}$-inch products to separate bins. Sand is dewatered in a drag classifier before delivery to the storage bin. Material over $1\frac{1}{2}$-inch in size is crushed by a set of 15- by 40-inch Allis-Chalmers rolls and returned to the main belt by a conveyor belt 30 inches wide and 62 feet long. Water is pumped from the river by a Byron-Jackson ''Rainmaker'' centrifugal pump through a 6-inch pipe against a 60-foot head. All equipment is driven by electric motors, which can be operated by remote control from a panel board. There are six storage bins 10 by 10 by 16 feet in size, for different sized materials. Trucks are loaded from gates beneath the bins. Loads are weighed on a Fairbanks-Morse platform scale. The plant is designed to handle 100 tons of material per hour. About 35 percent of the material processed is minus $\frac{1}{4}$-inch and is classed as sand. Few rocks are more than 12 inches in size, and 6 inches is an average maximum size.

The batching plant includes a steel hopper 30 by 14 feet on top and sloping to 4 by 6 feet at the bottom. It has three compartments for $1\frac{1}{2}$-, $\frac{3}{4}$-, and $\frac{1}{4}$-inch materials. Trucks are emptied into the hopper from a dirt-filled ramp. A Blaw-Knox scale beneath this hopper has three compartments which can be filled with the proper sized material in the amounts specified and discharged into a conveyor belt. Cement is added to the sand and gravel on the conveyor belt as it passes beneath a platform at the side of a cement-storage house 28 feet wide and 30 feet long. The cement is stored on pallets five sacks high which are picked up with a hand truck, moved to a hole above the conveyor belt, and emptied on the belt by slitting the paper sacks with a knife. The conveyor discharges this material into a steel hopper of 7 cubic yards capacity, from which it is loaded into the transit-mix trucks for delivery. A steel water tank of 2,500 gallons capacity is located above the batch hopper and supplies the water to fill the tanks on the transit-mix trucks. The batching plant has a capacity of 500 cubic yards in 8 hours. This plant supplied about 5,800 cubic yards of Class ''A'' concrete for the five sand slough bridges on U. S. Highway 99 E south of the plant. A concrete cylinder made with 45 percent $1\frac{1}{2}$-inch, 15 percent $\frac{3}{4}$-inch, and 40 percent sand, Permanente cement, and mixed with $5\frac{1}{2}$-gallons of water per sack of cement in a $4\frac{1}{2}$-cubic yard Yaeger transit-mix truck, had a compressive strength of 6,635 pounds per square inch in 28 days. Four men were employed at the plant November 3, 1947. Harold Eggleston is manager for Draper and Adams.

Liston Ehorn, 926 Jackson Street, Red Bluff, loads gravel from the east bank of the Sacramento River a short distance north of Highway 99 E. A Michigan dragline equipped with a 40-foot boom and a $\frac{5}{8}$-cubic yard bucket is used to load seven 5-cubic yard trucks. The gravel is used for roads, and the pit is operated only when gravel is needed. Six men are employed from time to time.

Richfield Concrete Products Company, Elmer D. Clary, owner, operates a concrete block manufacturing plant at Richfield, California, about

2 miles east of U. S. Highway 99 W. Washed sand, minus ⅜-inch mesh, is purchased from the Baker Trucking Company, whose pit is located about half a mile north on the south bank of Thomes Creek. Sand is dumped from the trucks into a 9- by 9- by 9-foot steel hopper which slopes to feed a bucket elevator. It is lifted about 35 feet and discharges into a steel hopper above a batch mixer. This hopper is 9 feet square on top and is divided into two compartments of 15 cubic yards capacity each, one for pumice and one for sand. The desired material is drawn into a second measuring hopper from which the specified quantities can be dropped into a Besser batch mixer of 50 cubic feet capacity. The mixer is driven by a 30-horsepower electric motor. Cement is poured into the mixer from standard paper bags and the water is measured from a steel drum. The mixed batch is dropped into a steel skip which is hoisted up an incline track to discharge into a steel hopper of 90-cubic foot capacity from which it is drawn to fill the three-block Besser Vibrapak machine. The blocks are unloaded from the machine with an air hoist and placed on steel racks. The racks are built of angle iron and have six shelves made of sheet steel ¼-inch thick. They hold 72 blocks each. The filled racks are lifted and transported to curing rooms by a Clark fork-truck. There are four curing rooms 13½ feet wide by 36 feet long, which holds 20 racks each. They are heated to 250° fahrenheit for 12 hours and are kept filled with live steam. Steam is supplied by an oil-fired 70-horsepower boiler. The plant has a capacity of 5,000 blocks in 8 hours. They are made in 4- by 8- by 16-inch, and 8- by 8- by 16-inch sizes. Six men are employed. E. W. Baxter is office manager, and L. Wright superintendent at the plant.

Wm. G. Taber and his son *Robert W. Taber*, P. O. Box 646, Red Bluff, load gravel from a bar on the east side of the Sacramento River about a quarter of a mile north of Highway 99 E. The land is owned by Roy Roberts of Red Bluff. Loading is also done from other pits along the river when they are more convenient. The gravel is dug with an International T.D.-9 tractor equipped with a Bucyrus-Erie ¼-cubic yard shovel. Pit run gravel is delivered in a 3-cubic yard or a 5-cubic yard dump truck. A small amount of gravel is screened by hand when required. The Tabers work alone and load about 40 cubic yards of gravel per day. About half of the gravel is used for concrete aggregate and half for roads and driveways. Gravel sells for $1.75 to $2.00 per cubic yard delivered in the Red Bluff area.

TRINITY COUNTY

Gold

Brown Bear mine includes 35 parcels of patented land in secs. 11, 12, 13, 14, 16, 24, T. 33 N., R. 8 W., M. D., assessed to E. E. Erich of Redwood City, California. It is leased with an option to purchase by the Western Gold Mines Company, Silas O. Silverman, president, Crown King, Arizona. An old caved adit on the Coon Dog claim was reopened in August 1947 and a vein 6 feet wide striking S. 80° E. and dipping 63° N. was developed. The vein is at the contact of diorite porphyry with slate. It includes quartz stringers and crushed fragments of both slate and porphyry, and a great deal of pyrite. Very little of the gold is free. The gold is associated with galena and calcite. The old milling plant at the Watt adit portal was remodeled to treat this ore. Trucks

dump the ore into a 200-ton storage bin. It is drawn from chutes onto a 3- by 6-foot shaking screen with 2-inch openings. Material over 2 inches in size is crushed to $\frac{1}{2}$-inch in a 9- by 21-inch jaw crusher driven by a 60-horsepower motor. The undersize from the screen and jaw crusher drops into a 100-ton bin. A belt conveyor feeder delivers the ore from the bin to a 42- by 48-inch Marcy ball mill driven by a 30-horsepower motor. It is ground to 75-mesh and fed into a Bendelari jig. The overflow from the jig goes to a rake-type classifier, from which the sand is returned to the ball mill. The slime flows to a 6-foot diameter Dorr conditioner, where cresylic acid, copper sulphate, and reagent Z-6 are added. The conditioned pulp is treated in six Denver Engineering Company flotation cells.

The hutch product from the Bendelari jig is fed to a 2- by 4-foot Wilfley table, from which the sand is returned to the ball mill circuit. The flotation and table concentrate is shipped by truck to the Empire-Star cyanide plant at Grass Valley, California, for treatment. The Brown Bear mine has been a noted gold producer and is described in earlier reports.[12]

Dave Rice is general superintendent, Austin Merrill mill superintendent, and Jesse Cuddeback mine foreman. Eighteen men are employed.

Clear Creek Gold Dredging Company (Enterprise Engineering Company), a partnership composed of W. F. Eubank and Walter Sivochenko of Douglas City, California, is operating a dragline dredge on Redding Creek in secs. 18, 19, T. 32 N., R. 9 W., M. D., on land leased from Ted Miller and Earl Johnson. The Bodinson-built dredge is on five steel pontoons making a hull of 36 by 46 feet and 42 inches deep. The trommel is 5 feet in diameter and 41 feet long. Water is pumped by a Fairbanks-Morse 10-inch centrifugal pump. The stacker belt is 30 inches wide and 50 feet long between pulleys. The Pan-American jigs used on Clear Creek by the Enterprise Engineering Company have been replaced by conventional sluice boxes with Hungarian riffles. Power is supplied by an International U-D18 engine and a 63 kilovolt-ampere Palmer generator. The gravel is about 10 feet deep above a soft slate bedrock. It is dug with a Model-60 Lima dragline with a 62-foot boom and a $2\frac{1}{2}$-cubic yard bucket. Operation started October 2, 1947 at this location. Nine men are employed.

Costa Ranch includes 876 acres of patented land owned by Frank and George Costa and others, and 80 acres held by location in secs. 9, 16, 17, 21, T. 34 N., R. 9 W., M. D. The loose bench and creek gravel along Rush Creek is about 35 feet deep above a hard cemented gravel. Water is obtained from Rush Creek through about 1 mile of ditch and is delivered under 125-foot head to two giants fitted with 5-inch nozzles. The loose gravel is worked down to the cemented gravel and washed through 50 feet of sluice boxes 40 inches wide and 48 inches deep and fitted with block riffles. The tailing is stacked with a bulldozer. Equipment includes a D-8 Caterpillar tractor with a power unit; a D-7 Caterpillar bulldozer with a Hyster winch; a 300-ampere portable Lincoln arc welder; a G.M.C. 5-ton tandem truck; and an Allis-Chalmers 75 tractor with bulldozer. A water right is owned for 63 cubic feet per second from

[12] Averill, C. V., Gold deposits of the Redding and Weaverville quadrangles: California Div. Mines Rept. 29, pp. 13-15, 1933. . . Trinity County, California Div. Mines Rept. 37, pp. 27, 75, 1941.

Rush Creek. Frank and George Costa were working the property alone in May 1947.

Junction City Mining Company, 685 Sixth Street, San Francisco, California, Harvey Sorenson, president, is operating a bucket-line dredge on the Trinity River 1½-miles below Junction City in sec. 1, T. 33 N., R. 11 W., M. D. The dredge is built on 31 steel pontoons making a hull 120 feet long, 52 feet wide, and 8 feet deep. Seventy-two buckets of 9½ cubic feet capacity are pulled by a 200-horsepower electric motor. The trommel screen is 7 feet in diameter, 37 feet long with 27 feet of ¼-inch to ½-inch holes. It is rotated by a 35-horsepower motor. Water is supplied by a 10-inch high-pressure pump driven by a 100-horsepower motor; a 10-inch low-pressure pump driven by a 20-horsepower motor, and a 4-inch pump driven by a 35-horsepower motor. The stacker belt is 36 inches wide and 135 feet long and it is driven by a 50-horsepower motor. The winch is driven by a 35-horsepower motor. There are ten cross sluices and three downstream sluices on each side of the trommel. They are 30 inches wide and are fitted with Hungarian riffles. The gravel is 18 to 21 feet deep above a hard serpentine bedrock. The dredge can dig to a maximum depth of 35 feet below water line. Derby Wilson is superintendent and S. M. Williams dredgemaster at Junction City. Twenty-one men are employed.

Mires and Underseth Dredge. Roy Mires and Carl Underseth, owners, are operating on a strip of land 8 miles long on Coffee Creek in secs. 28, 29, 30, 31, 33, 34, T. 38 N., R. 9 W., M. D. The land is leased from Mrs. E. S. Joseph, Helen Gates, and Evelyn Spieglman. The gravel is about 18 feet deep above a hard serpentine bedrock. The dredge is built on 25 steel pontoons making a hull 100 by 50 by 7 feet. Eighty-two buckets of 6 cubic feet capacity are pulled by a 100-horsepower electric motor. The spud is 22 by 32 inches and 50 feet long. It weighs about 20 tons. The trommel is 6 feet in diameter and 30 feet long and has 22 feet of screen. It is driven by a 40-horsepower electric motor. The stacker belt is 30 inches wide and 40 feet long and is driven by a 25-horsepower motor. The eight cross sluices and two downstream sluices on each side of the trommel are 28 inches wide and are fitted with rubber covered wooden riffles. Each cross sluice has one section in which mercury is used. The gold is fairly coarse and most of it is recovered with mercury in the distributor. Many boulders are by-passed from the stacker belt by a chute at the end of the trommel. Electric power for operating the dredge is obtained from a General Electric 350-kilowatt generator driven by a Busch-Sulzer Bros. diesel engine. There are 2 miles of transmission lines. Equipment includes an Allis-Chalmers H.D.-14 bulldozer; International Harvester U.S.9 engine driving a Palmer self-regulating alternator; a P & H arc welder mounted on a steel trailer bed; and an Oxweld medium-pressure acetylene generator of 50 cubic feet capacity. The power plant is housed in a new frame building. Four steel tanks 7 feet in diameter and 25 feet long are used for diesel oil storage. Eight new buildings have been built including two bunkhouses, three dwellings, an office, and a garage. Twenty men are employed on three shifts. Ed Siligo is dredgemaster.

Placer Exploration Company, Box 113, Palermo, California, is operating a dragline dredge on the Trinity River about 2 miles below Douglas City in sec. 2, T. 32 N., R. 10 W., M. D., on land leased from Carl Tout. Equipment includes a Northwest Model-85 dragline with a 66-foot

boom and a 2-cubic yard bucket. Power is furnished by a Murphy 160-horsepower diesel engine. The washing plant has seven steel pontoons 8 by 36 feet and 42 inches deep. The trommel is 5 feet in diameter by 35 feet long and has 25 feet of ½-inch holes. The stacker belt is 36 inches wide and 60 feet long between pulleys. Ten side sluices 18 inches wide and 2 downstream sluices on each side are fitted with Hungarian riffles. Water is supplied by a Krouch No. 10 centrifugal pump. Power for the washing plant is obtained from a D-13,000 Caterpillar diesel engine. Walter Laswell is dredgemaster.

Thompson Divide Mining Company, A. L. Damon, general manager, 1612 Oregon Street, Redding, is operating Dredge No. 1 on the Trinity River in sec. 22, T. 35 N., R. 8 W., M. D., on the Nugget placer, which was purchased from L. A. Grange. The washing plant is built on five steel pontoons making a hull 30 by 40 feet. The trommel is 54 inches in diameter and 28 feet long with 18 feet of perforations. The stacker belt is 36 inches wide and 50 feet long between pulleys. A 6-inch centrifugal pump furnishes the wash water. There are eight side boxes and two downstream sluices on each side fitted with Hungarian riffles. Power is furnished by a D-13,000 Caterpillar diesel engine. The Model-655 P & H dragline has a 55-foot boom and a 1¼-cubic yard bucket. From 4 to 12 feet of overburden is stripped from the gravel by the dragline. The gravel is 12 to 13 feet deep above a soft black slate bedrock. It is being prospected by drilling 6-inch holes with a Keystone drill. Holes are drilled at 50-foot centers where the channel is 200 feet wide, and 100-foot centers where the width is up to 1,300 feet. The interval between rows of holes is 500 feet. Holes are from 22 to 50 feet deep. Guy B. Slack is in charge of the operation. Thirteen men are employed in three shifts.

Dredge No. 2 is operating on the Trinity River in sec. 8, T. 33 N., R. 8 W., M. D., on ground owned by the Trinity River Mining Company of Berkeley. Equipment includes a 120B Bucyrus-Erie dragline powered by a 200-horsepower electric motor and equipped with a 5-cubic yard bucket and a 90-foot boom. The washing plant is built on nine 8- by 36- by 4-foot steel pontoons, and two 4- by 4- by 16-foot pontoons have been placed on each side. The trommel is 60 inches in diameter and 36 feet long with 25 feet of ½-inch holes. The 36-inch stacker belt is 115 feet long between pulleys. Water is supplied by 10-inch and 12-inch centrifugal pumps. The gravel is about 13 feet deep above a decomposed diorite at this location. About 3,000 cubic yards are dug per day. The dredge was moved to this location from the south side of the river, where the cement gravel was from 2 to 11 feet thick and had to be drilled and blasted. Holes were drilled with wagon drills at about 6-foot intervals and blasted with 23 percent Atlas stump powder. It was very hard digging and the wear on bucket teeth and equipment was excessive. Oscar A. Herbert is dredgemaster. The crew includes 17 men.

THE SPECTROGRAPH AND POLAROGRAPH

By John Herman *

OUTLINE OF REPORT

ILLUSTRATIONS

THE SPECTROGRAPH AND POLAROGRAPH—TWO IMPORTANT TOOLS FOR ROCK AND MINERAL DETERMINATION

Introduction

In 1620, Kepler noticed the bands of color when light was passed through a prism. In 1666, Newton used a circular aperture in passing light through a prism and got sharper separation of the spectrum from red to violet. In 1802, Wollaston first used a slit and noticed lines in the spectrum. Later Fraunhofer found many lines in the solar spectrum. In 1859, Bunsen, inventor of the bunsen burner, and Kirckhoff actually made a spectroscope for observing the spectrum and found a long list of

* Consulting spectrographer-chemist associated with Smith-Emery Company, Los Angeles, California. Manuscript submitted for publication March 1, 1948.

Ed. Note. The State Division of Mines has recently received two valuable pieces of research equipment for use in the mineral investigations which are carried on by the Division. One is a grating-type spectrograph made by the Applied Research Laboratories. The other is a Heyrovsky-Shikata polarograph. Both are gifts of the author, Dr. John Herman, of Los Angeles. The polarograph received by the Division of Mines is one used by its inventor, Dr. J. Heyrovsky, when he was in the United States. The Division of Mines is deeply indebted to Dr. Herman for these splendid pieces of equipment.

Table 1. List of elements determined by arc spectrograph.

Element	Wave length of line most used	Maximum sensitivity percent
Ag (silver)	3280.7	.0001
Al (aluminum)	3961.5	.0001
As (arsenic)	2780.2	.01
Au (gold)	2675.9	.001
B (boron)	2497.7	.001
Ba (barium)	4554.0	.0001
Be (beryllium)	3131.6	.0001
Bi (bismuth)	3067.7	.0001
Ca (calcium)	4226.7	.0001
Cb (columbium)	4059.0	.001
Cd (cadmium)	3261.0	.001
Co (cobalt)	3453.5	.0001
Cr (chromium)	4254.3	.0001
Cs (caesium)	4593.2	.001
Cu (copper)	3247.5	.0001
Fe (iron)	3020.6	.001
Ga (gallium)	2943.6	.0001
Ge (germanium)	3039.1	.001
Hf (hafnium)	2820.2	.01
Hg (mercury)	2536.5	.01
In (indium)	4511.3	.0001
Ir (iridium)	3220.7	.01
K (potassium)	4044.2	.1
Li (lithium)	3232.7	.001
Mg (magnesium)	2852.1	.0001
Mn (manganese)	4030.8	.0001
Mo (molybdenum)	3132.6	.0001
Na (sodium)	3302.3	.01
Ni (nickel)	3414.8	.0
Os (osmium)	2909.1	.001
P (phosphorus)	2555.0	1.0
Pb (lead)	2833.1	.001
Pd (palladium)	3404.6	.001
Pt (platinum)	3064.7	.001
Ra (radium)	3814.4	.001
Rb (rubidium)	4201.8	.001
Re (rhenium)	3460.5	.001
Rh (rhodium)	3434.9	.001
Ru (ruthenium)	3499.0	.001
Sb (antimony)	2598.1	.0
Sc (scandium)	3911.8	.01
Si (silicon)	2881.6	.0001
Sn (tin)	3175.0	.001
Sr (strontium)	4077.7	.0001
Ta (tantalum)	3311.1	.01
Te (tellurium)	2385.8	.001
Th (thorium)	4381.9	.01
Ti (titanium)	3372.8	.0001
Tl (thallium)	3775.7	.001
U (uranium)	4241.7	.1
V (vanadium)	3184.0	.001
W (tungsten)	4008.8	.001
Yt (yttrium)	3242.3	.01
Zn (zinc)	3345.5	.01
Zr (zirconium)	3392.0	.01
15 rare earths		.02

spectrum lines which each element gave. Since then, improved spectroscopes have been made and in later years, spectrographs were made and first used by astronomers who photographed the spectrum of stars. For this purpose, the grating spectrograph was used generally instead of the prism instrument. This consists of a series of lines pressed into a metallic reflecting surface. In the instrument of the State Division of Mines there are 24,000 lines to the inch. By the proper procedures, the light from a star is broken up and reflected onto a photographic film. Each element makes its individual spectral lines. Commercial laboratories borrowed the idea from astronmers and use an electric arc, a slot, and either a prism or a grating, and photograph the result on a photographic plate or film. The sample is burned in the electric arc at a temperature about three-fourths as hot as the surface of the sun. Each element has its individual spectral lines. It was not until 1935 that grating spectrographs (pl. 57), as made by the Applied Research Laboratory, instead of prism instruments, began to come into commercial use. Since then, densitometers have come into general use, and not only the arc spectrograph, but also the spark spectrograph, in which the spectral lines from the material being tested are photographed or even recorded directly. Instruments costing as much as $40,000 are used in the steel industry and in making special alloys.

New as is the polarograph, the number of articles written about it since 1922 has now passed 1400, and would be considerably larger if all information could be released.

The polarograph was invented by Professor J. Heyrovsky, head of the Department of Physical Chemistry at Charles University, the 600-year old institution in Prague, Czechoslovakia. It was first reported by him in 1922. He gives great credit to his teacher, the late Professor Kucera, who in 1903 found certain interesting facts in his researches on the weight of a falling drop of mercury. Kucera found very strange behavior in certain electrolytes, and in 1918 suggested to his student, J. Heyrovsky, that he continue the studies of the falling drop of mercury under electrolysis. The result was the polarograph as it is known today in its multitude of applications. In 1933, the writer met Professor Heyrovsky at the California Institute of Technology and made certain suggestions. Professor Heyrovsky was familiar with some of the writer's work and suggested a trip to Prague to work with him. The polarograph used by Professor Heyrovsky at that time is the one now owned by the State Division of Mines (pl. 59).

General Discussion

A spectograph built in 1935 by Applied Research Laboratories, was the first to use the projection comparator (pl. 58) which has since come into universal use.[1]

The first conviction of a counterfeiter by the use of the spectograph was made in Los Angeles, by comparing splotches of metal on the counterfeiter's stove and the metal of the coins themselves. The two matched perfectly.

[1] "In 1935, the John Herman Laboratories of Los Angeles, purchased a spectrograph and . . . (the) newly designed projection comparator. The projector, new in itself, embodied two valuable ideas suggested in principle by Dr. Herman; a dual projector arrangement permitting two images to be thrown on the same screen and the use of a master plate, the former appearing directly over the latter on the same screen. This first use of dual projection and a master plate represented a real advance in making spectrographic analysis practical." *Spectrographers News Letter, vol. II, No. 2, October 1946.*

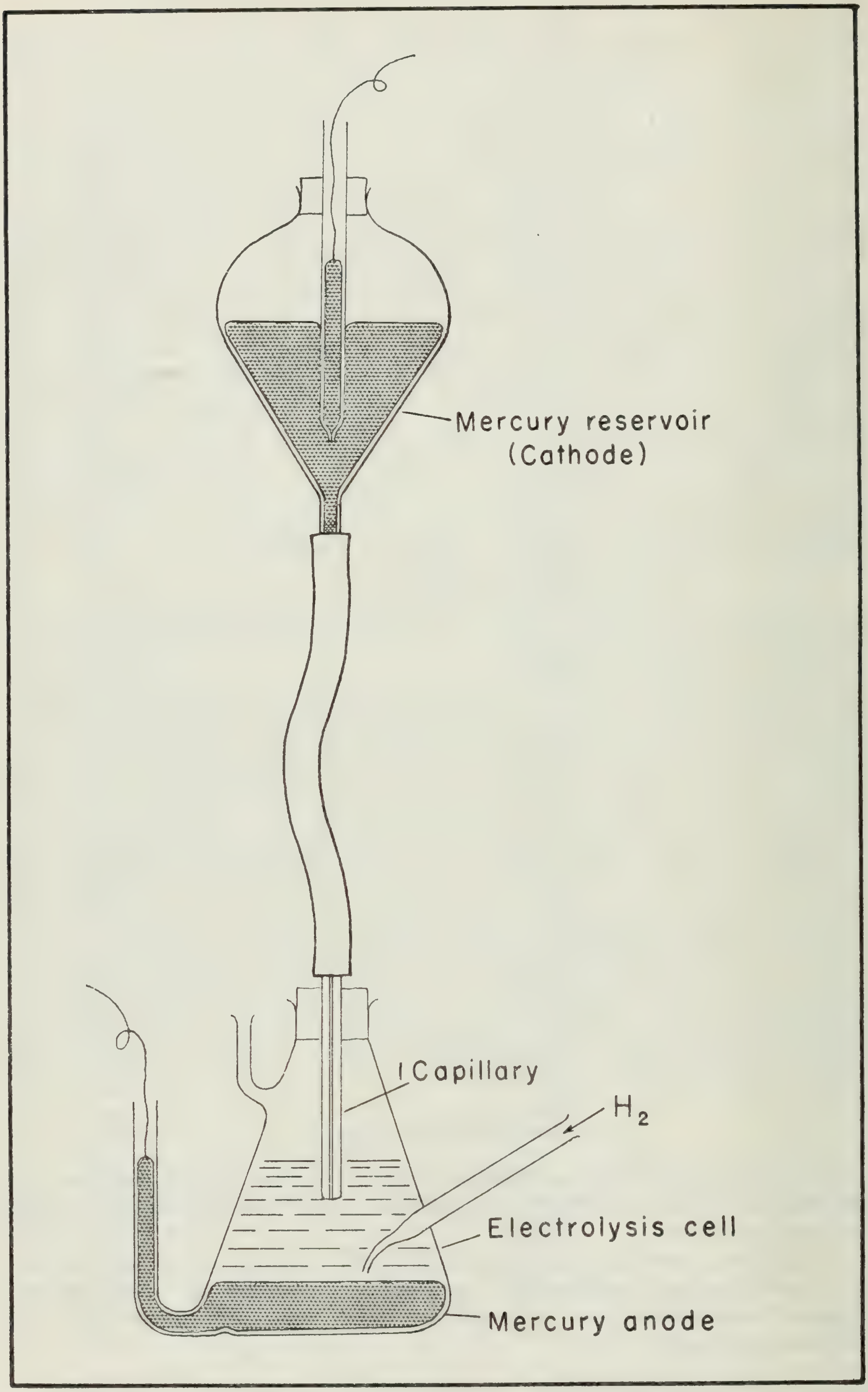


FIGURE 1. Simple polarograph cell designed by the inventor, Dr. Heyrovsky. Drawing shows how connection is made to the cathode and the anode. A neoprene tube is used in forming the mercury column. Air is removed by bubbling nitrogen or hydrogen through cell. *From Kolthoff and Lingane.*

The spectrograph has frequently been used to identify paint on an automobile which had been hit by another in a collision. The two samples in such cases match perfectly (pl. 56*A*).

The polarograph now owned by the State Division of Mines is the one used by Professor Heyrovsky while in the United States under the sponsorship of the Rockefeller Foundation in 1933. It was demonstrated at various colleges, principally at California Institute of Technology where the first quantitative test of Vitamin C was made. Even at that time, polarographic tests could distinguish the albumin of a Caucasian from that of a Negro. Valence and the course of oxidation and reduction reactions could be followed. A continuous polarograph was used in Prague to check the purification of the city water. Failure to add the proper chemicals at the proper time was recorded on a graph. Medical clinics, wineries, makers of alloys, and manufacturers of chemicals make use of the instrument.

A Berlin laboratory made a small quantity of especially pure zinc; in trying to get an analysis, they found they would have to sacrifice about a third of their stock for the usual chemical analysis, which would take more than a week. A plane delivered a sample of half a gram to Prague and the results were wired back the same day with a greater degree of accuracy in thousandths of 1 percent than any chemical test could do on the small amount of impurities reported.

Most of the larger universities now have the instrument. A list of the names of the users would be much the same as a list of those who have done the most in atomic research.

The function of the polarograph depends on the facts that: (1) each chemical substance has a fairly definite decomposition voltage; (2) by using a falling drop of mercury with its constantly renewed surface, the solution in contact with the drop, used as a cathode, becomes exhausted, thus limiting the current; and (3) the amperage is directly proportional to the concentration of the solution. These are the underlying principles of recorded current-voltage curves for quantitative analysis.

Application and Description

A considerable section of this article will concern both the spectrograph and polarograph, as both are devoted largely to the detection and estimation of very small percentages of the materials being analyzed.

The spectrograph is a photographic recording spectroscope especially suited for detecting very small amounts of the metallic and most of the non-metallic elements. Most substances may be detected in amounts as low as 0.001 percent. It is used as a preliminary for quantitative work. Prospectors find practically all they seek, outside of gold and the platinum group, in a single spectrographic analysis. However, if a precious metal button is made by ordinary assay methods and spectrographed separately, the whole range is covered. Then they know what to assay for.

The polarograph is as sensitive as the spectrograph and furthermore is 98 percent accurate in quantitative determinations. It is not used as universally as the spectrograph because at most only six elements can be polarographed at one time after they have been suitably treated. For accurate work, however, it excels the spectrograph.

Therefore, on metallic substances, the spectrograph should be used as a preliminary to quantitative chemical work, or to discover materials

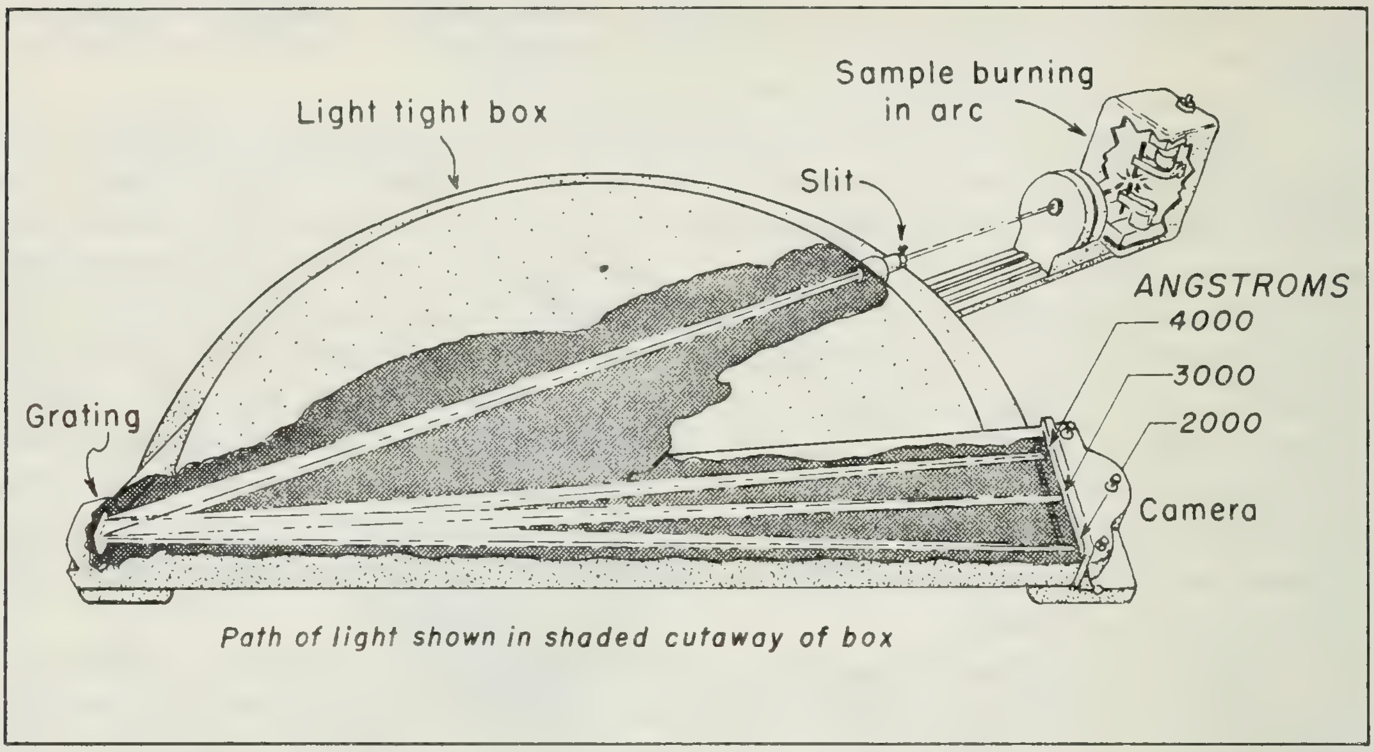


FIGURE 2. Diagram showing the grating spectrograph. *Courtesy of the Applied Research Laboratories*

overlooked; and the polarograph should be used on quantitative determinations of materials of low percentage content, or where other difficulties are encountered in standard work. Animal, vegetable, and mineral substances can in many cases be analyzed at the same time. The polarograph has a multiplicity of uses which will be discussed in the following pages.

A great deal of study has enabled some of the initial difficulties met with when the polarograph was invented, to be turned to advantage. For instance, at the start of the decomposition of a constituent in the solution, there is normally an extremely high wave, due partly to the concentrations of ions at the dropping electrode and partly, in some cases, to a very rapid agitation at the interface between the mercury cathode and the electrolyte. It breaks as the voltage increases and the curve comes down to normal. This has been utilized to measure certain reactions but is a nuisance in most cases. These rises are called maxima. Many of them can be suppressed by filtration or by adding a 0.01 percent gelatin solution. Minute amounts of methyl red or a very large number of suppressants have the same effect.

The spectrograph burns from 10 to 50 milligrams of material in a miniature electric arc using $\frac{1}{4}$-inch graphite electrodes. The temperature vaporizes the material in 2 or 3 minutes. The light emitted from the burning sample passes first through a lens, and then through a slit one or two thousandths of an inch wide, and strikes a grating, by which it is reflected back, broken up into its wave lengths. The resulting spectrum, when photographed on ordinary motion-picture film, appears as lines, each line in a definite position corresponding to its wave length.

Comparison is made with a standard film on which there appear spectra of iron as a reference, and the principal lines of all the elements sought drawn on the film for matching with the unknown. The spectrograph has recently been developed to give results automatically in a matter of a few minutes on several constituents of steel in a single determination. It has been used by the Kirk Company in the making of the

alloy Kirksite. In some cases, under extremely uniform conditions, an accuracy of 90 to 95 percent has been attained.

In polarographic analysis, an electric current is applied to a solution beginning with a voltage of zero and gradually increasing to the decomposition point of water. Each time the decomposition point of any constituent of the solution is reached, there is a sudden quantitative increase of the current proportional to the concentration of that constituent. When the decomposition voltage of the next compound is reached, there is another sudden increase of the current which is registered with suitable instruments as current voltage curves. It depends on ionic phenomena and is sometimes called "the chemical spectrum." The polarograph is sensitive to a concentration of about one part of the substance sought in a million of solution. The accuracy is about 98 percent on anything which has 100 or more parts per million of solution.

In the polarograph, the voltage is regulated by resistances. A revolving drum registers the current voltage curves, a revolving wheel takes care of the resistance which regulates the steadily increasing voltage, and a mirror galvanometer with a beam of light shining upon it furnishes the means of measuring and recording the electric current. The revolution of the film shows the voltage, and the height of the curve the amperage.

The chief factor in determining the height of the curve is the atomic weight and valence of the element being analyzed. A light metal will give a curve twice as high as another of the same valence which has twice the atomic weight. A metal which is reduced by two valences gives a height of curve double that of another which is reduced only one valence. Gold reduced from $AuCN_3$ to $AuCN$ gives twice the height of curve as $AuCN$ reduced to Au.

Various solutions give not only different voltages for the decomposition, but, in most cases, they change the difference between the voltage required for different elements.

If there is interference between the metals present when using an HCl solution or a solution of any strong acid, one can then use any number of solutions for suppressants, such as an alkaline solution, a weak acid solution like tartaric acid, a neutral or alkaline tartrate, an ammonical solution, or a neutral solution like KCl.

An example may be found in the section on polarographic studies on gold which, in the common compounds, is deposited below the potential of mercury and is changed to complexes which require a higher potential than mercury.

Details of Operation of the Polarograph

To those who are familiar with the flow of electricity through wires it seems strange that there should be any variation of the quantity of flow which is proportional to the voltage. This is truly approximated by the current passing through different electrolytes which are used to carry the current through the solution itself.

However, it is the variations of the current through the decomposition of reducible and oxidizable electrolytes that give us our uses of the polarograph.

There is a slight current flowing through the solution at the lowest voltage which rises slightly and gradually as the voltage is increased.

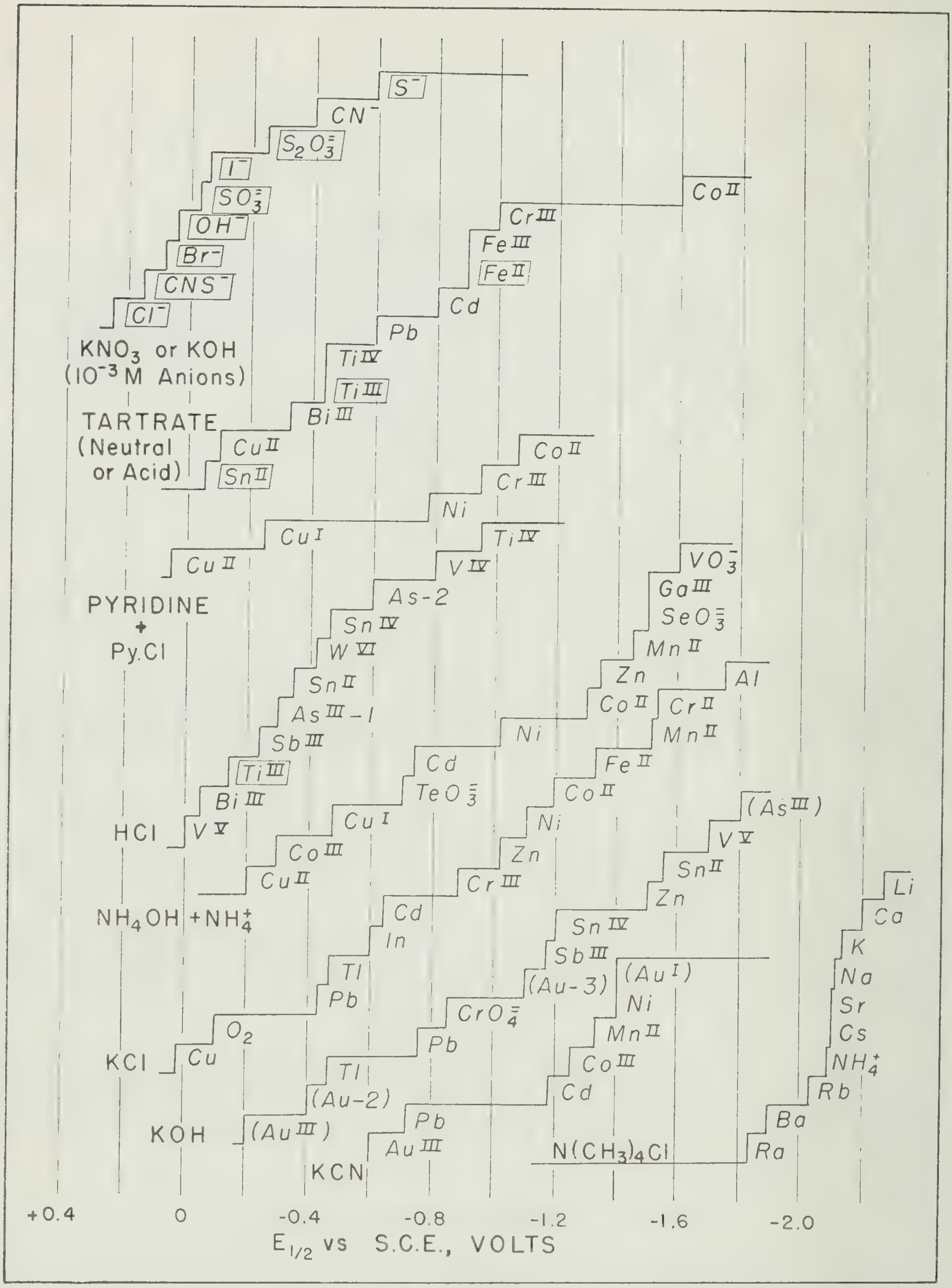


FIGURE 3. Table of elements showing their decomposition voltage in various supporting electrolytes. Anodic waves are indicated by enclosing the symbol of the element or ion in a parallelogram. The anodic waves of the ions in the uppermost series are usually determined in 0.1 to normal KNO_3, with the exception of sulphide and cyanide ions which are determined in 0.1 to normal KOH. *From Kolthoff and Lingane.*

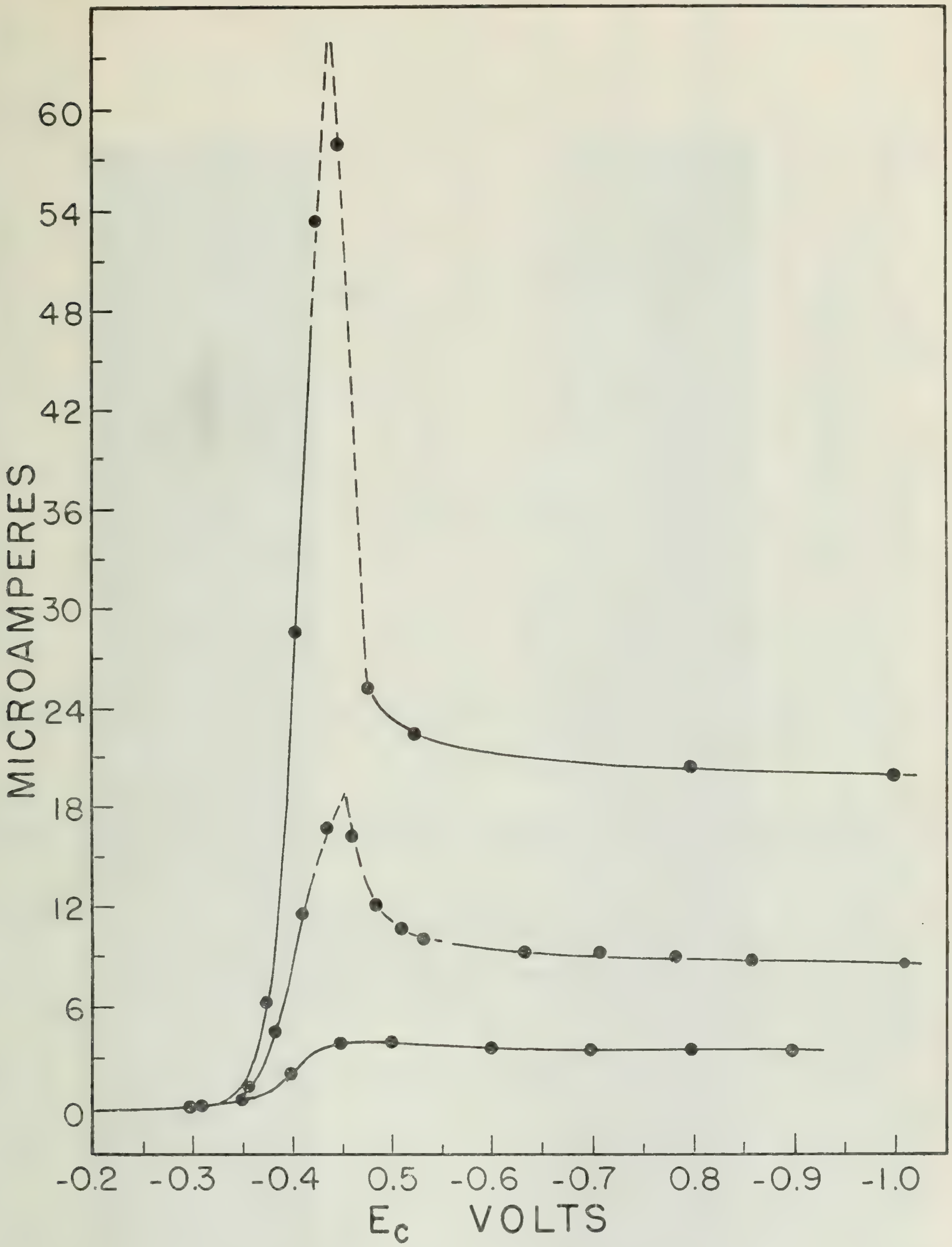


FIGURE 4. Diagram showing increase in microamperage maxima with increase in concentration. The top curve was a concentration of 2.3 × 10^{-3} molar; bottom curve was 3.3 × 10^{-4} molar; central curve was 1 × 10^{-3} molar. The weakest curve had no rise like the others. *From Kolthoff and Lingane.*

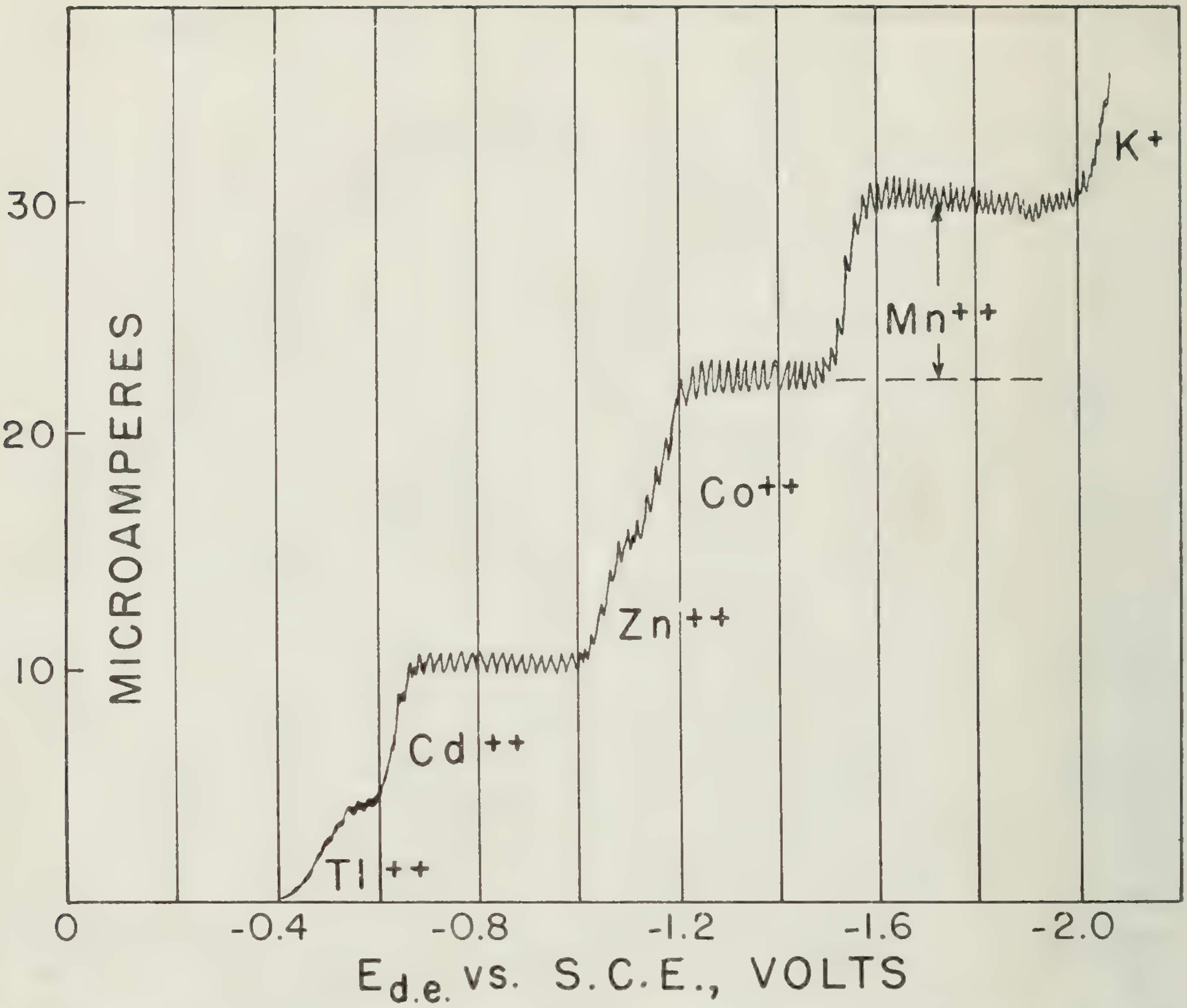


FIGURE 5. Polarogram of a solution containing several metal ions, each at a concentration of approximately 0.001 molar in 0.1 normal KCl containing 0.1 percent gelatin. *From Kolthoff and Lingane.*

In addition, there is a sharp rise as the decomposition voltage of the most reducible constituent of the solution is reached. Since each drop of mercury has a surface area of about 2 square millimeters, the reducible material surrounding the drop of mercury is rapidly exhausted and the current levels off.

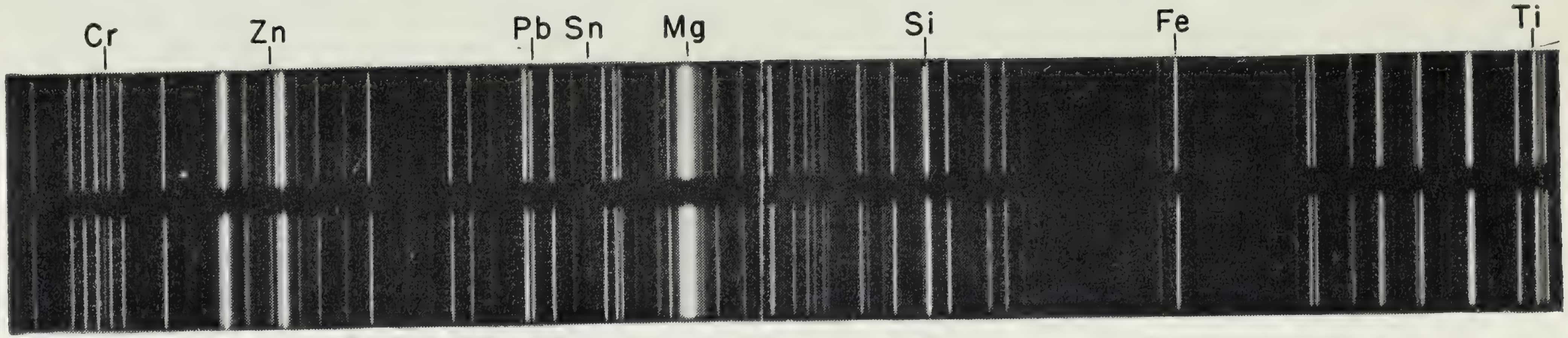
The rise in curve is directly proportional to the concentration of the reducible material. The mercury solution is constantly being renewed so conditions are constant. When the voltage at which the next decomposition takes place is reached, there is another rise in current. This is repeated each time a decomposition voltage is reached.

The polarograph shows clearly how and why two or more metals can be deposited simultaneously and in what definite ratio. Thus a bearing metal is made from lead by electrolytically depositing calcium as an alloy with it. Even one-half of one percent calcium with the lead hardens it greatly.

The polarograph is used for determining practically all of the common metals and several of the rare earths. A rapid determination of copper, zinc, iron, lead, and nickel can be made in brass and other alloys.[2] Lingane [3] also describes similar procedure for tin, lead, nickel, and zinc

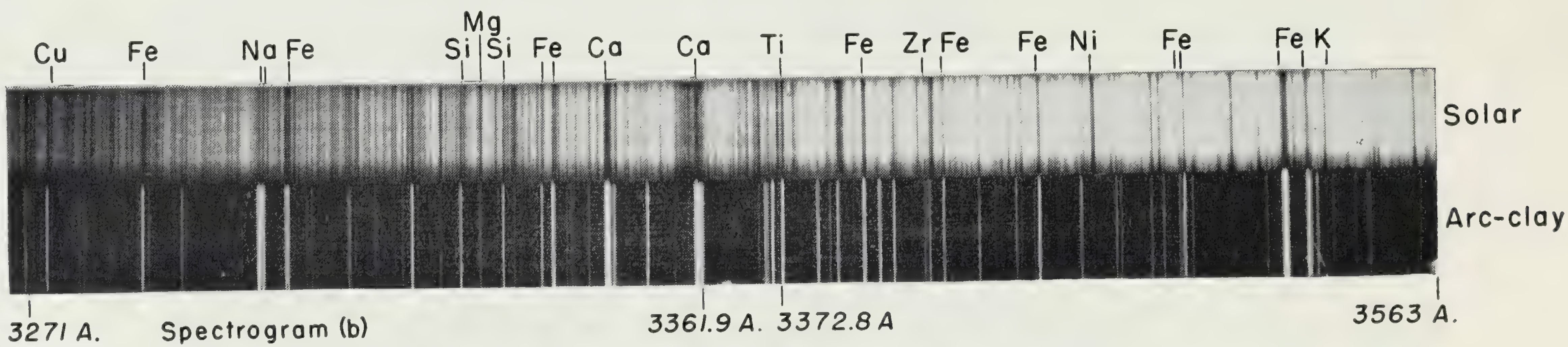
[2] Kolthoff, I. M., and Lingane, J. J., Polarography, pp. 276-290, Interscience Publishers, Inc., 1941.

[3] Lingane, J. J., Systematic polarographic metal analysis, determination of tin, lead, nickel, and zinc in copper-base alloys: Ind. and Eng. Chem. Anal. Ed., vol. 18, pamph. 7, July 1946, p. 429.



A, SPECTROGRAM OF PAINT SCRAPINGS

(1) Paint on car body. (2) Paint on fender. Note the perfect matching of spectral lines



B, SPECTROGRAM SHOWING COMPARISON OF SOLAR SPECTRUM WITH A CLAY SPECTRUM

Note the bright and dark lines are reversed in both cases so that the white lines of the clay match with the dark lines of the solar spectrum. The elements shown in this section of the spectrum are identical in the clay and sun. *Photograph by T. C. McBurney*

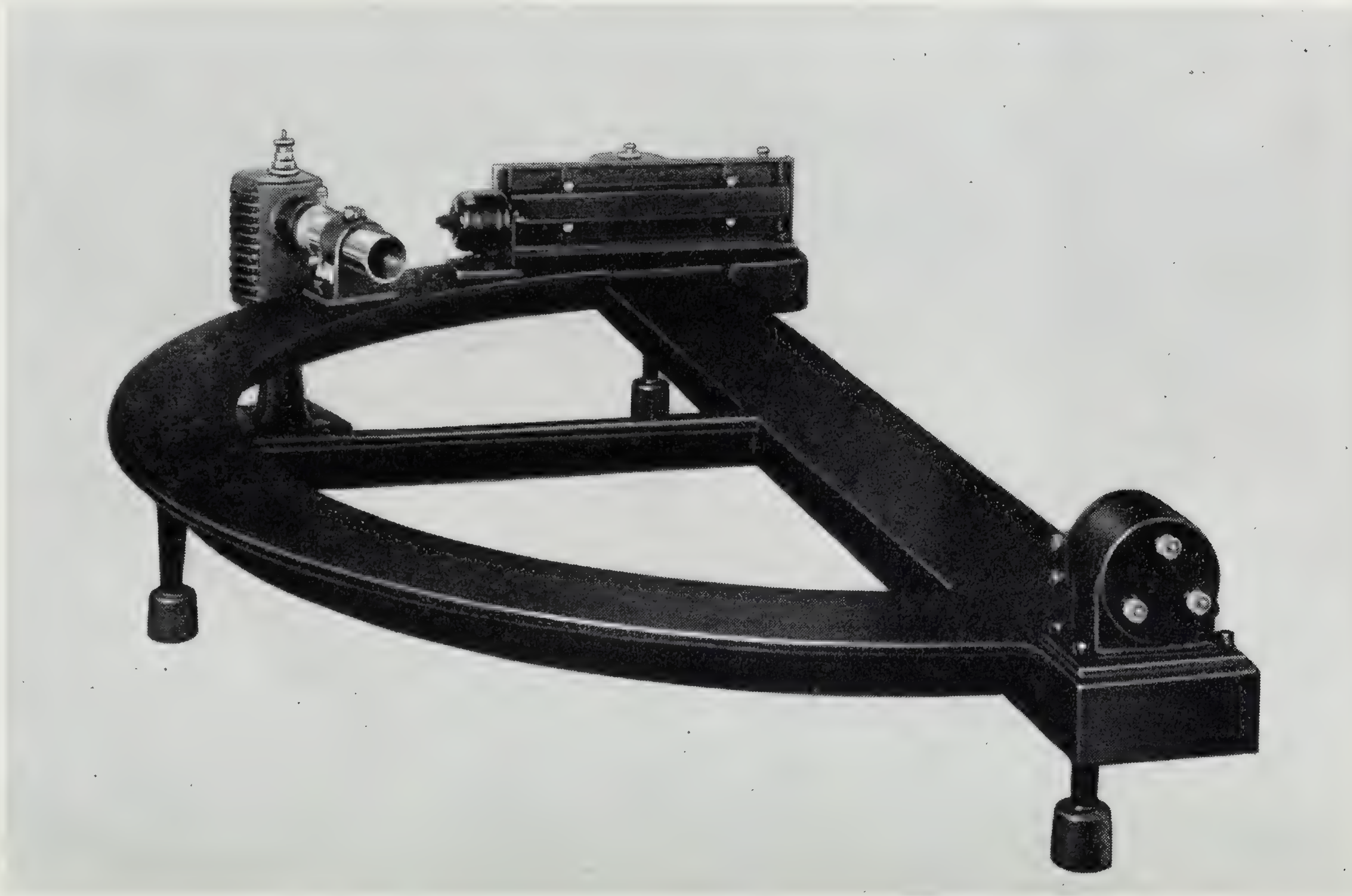


PHOTO SHOWING 1.5-METER SPECTROGRAPH
Photograph by courtesy of the Applied Research Laboratories

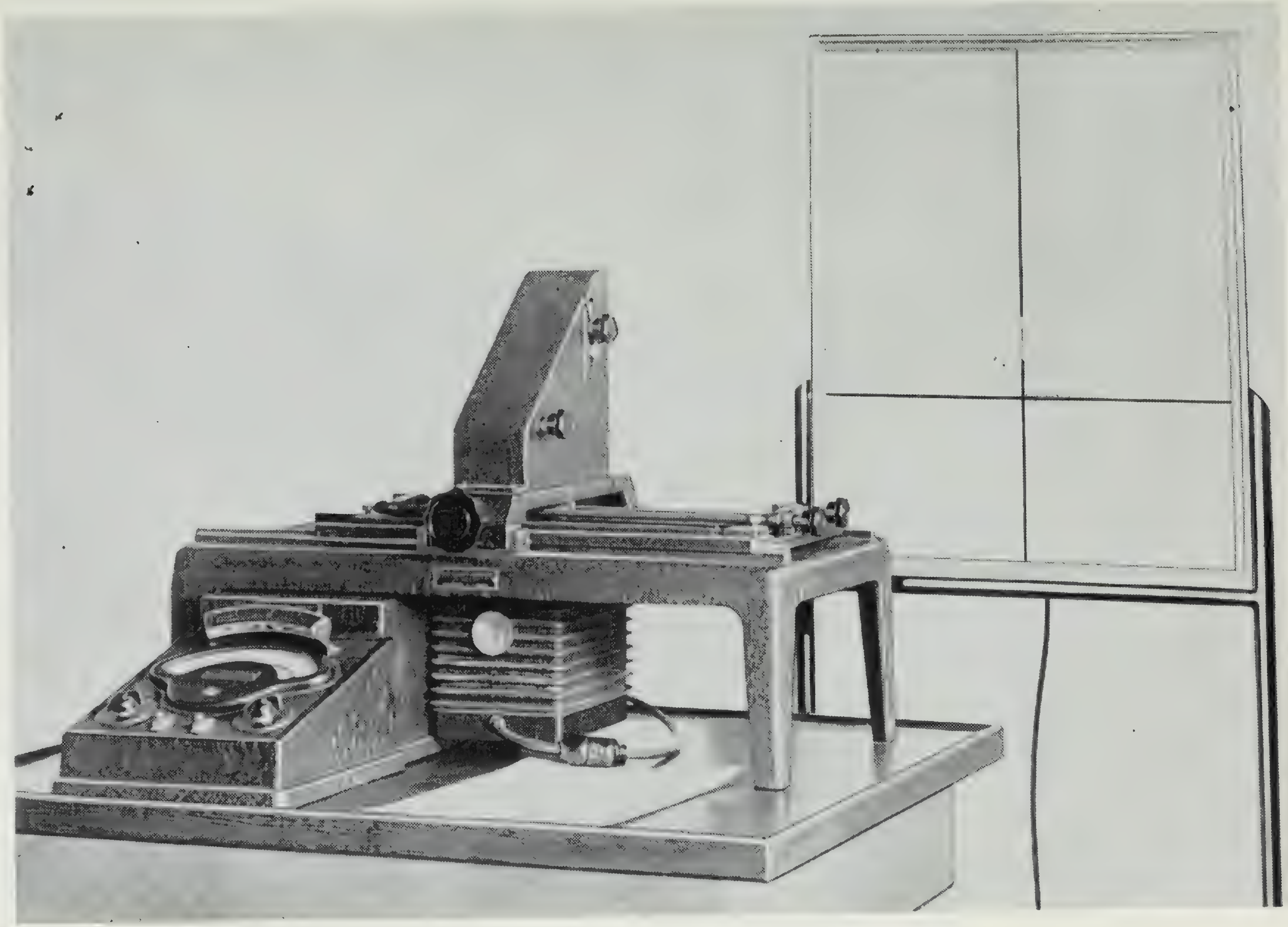
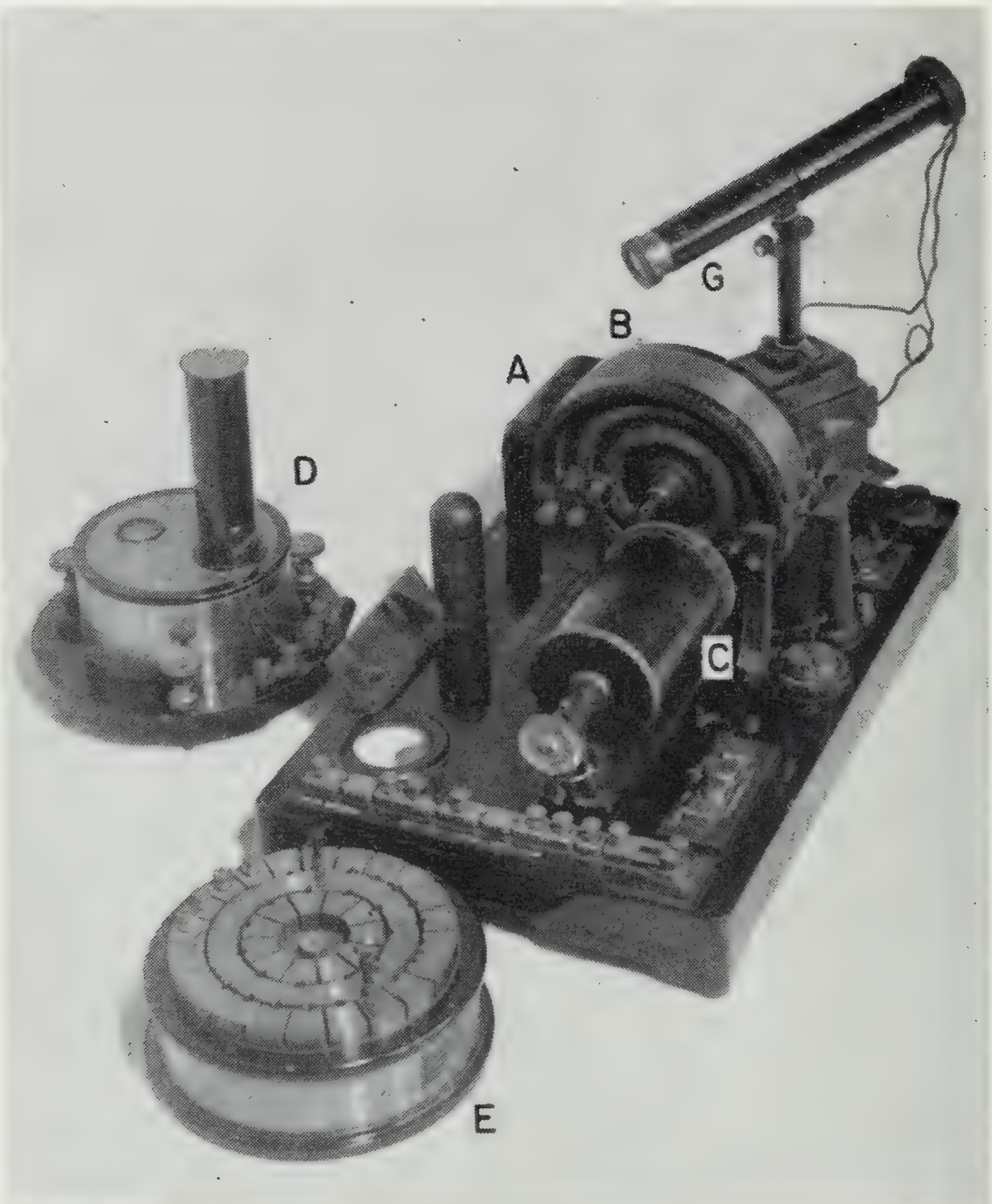


PHOTO SHOWING PROJECTION COMPARATOR
Photograph by courtesy of the Applied Research Laboratories



THE HEYROVSKY-SHIKATA POLAROGRAPH

The potentiometric bridge *B* is rotated by small motor *A*, which also rotates a roll of photographic paper contained in cylinder *C*. *G* is a galvanometer lamp which projects a thin beam of light onto the mirror of the galvanometer *D*, from which it is reflected to the photographic paper. The galvanometer is provided with a shunt *E*, for regulating its sensitivity. *Photograph by R. A. Crippen.*

in copper base alloys. Magnesium alloys can be analyzed readily for aluminum, zinc, maganese, and lead. Lingane developed many methods at the Mallincrodt Laboratory of Harvard University.

Uses in organic chemistry will be touched on briefly because one branch of science often borrows from another and there can often be departmental cooperation. Reducible organic substances can be determined by the polarograph in the same solution with inorganic substances, and both can be recorded. A notable example of using a combination of organic and inorganic substances is the work done by Dr. R. Brdicka,[4] of Charles University, in cancer research, some of which was done by him in California in 1935, under the auspices of the Rockefeller Foundation. He found that the sulphide and sulphydril groups in the protein in the blood could be determined in a union with cobalt by polarographic method. These groups were deficient in the blood of cancer patients.

He has now extended his work to the measurement of an excess of decomposition products from cancer patients. The polarograph is now in wide use for such purposes as well as in vitamin research.

Recent extension of polarographic studies to substances which are more reducible than mercury consists of the use of very dilute mercury amalgams for the dropping mercury electrode, so that the reactions start below the potential of mercury alone, and result in both anodic and cathodic reactions in a single operation of the polarograph.

The polarograph can be used in any industry where minute amounts of metals are to be analyzed. The paint industry finds use for it, as do also the ceramic and glass industries.[5] Progress of both organic and inorganic reactions can be followed rapidly with the polarograph, especially with the recording type.

The polarograph can be used in determining the absorbing power of colloidal material, like fullers earth, very rapidly and accurately. The fullers earth itself has no effect on the current but the absorption of active chemical ingredients reduces their amount in the solution.

Principles of the Polarograph

The polarograph has means of using almost any desired fraction of the sensitivity of the mirror galvanometer, which is sensitive to about two to four billionths of an ampere. This is to make use of varying concentrations and to make the resulting curves various sizes.

Very weak solutions of the material being analyzed give a shorter period between the beginning and end of the curve of any one constituent sought. This period usually varies between 0.06 and 0.2 volts. However, there is a rapid rise of the line due to the supporting electrolyte when using approximately the full sensitivity of the galvanometer. With slightly more concentrated solutions, a lower sensitivity is used which makes a lesser slope of the increase in current due to the supporting electrolyte. This advantage is taken at the cost of a wider voltage spread, although the middle point used in measuring voltage remains the same.

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[4] Brdicka, R., Application of the polarographic effect of proteins in cancer diagnosis: Nature, vol. 139, p. 330, 1937.

Brdicka, R., Polarographic investigations in serological cancer diagnosis: Nature, vol. 139, p. 1020, 1937.

[5] Abraham, B. M., and Huffman, R. S., A polarographic method for lead and zinc in paints: Ind. and Eng. Chem. Anal. Ed., vol. 12, p. 656, 1940.

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Improvements have been made by using balancing currents as devised by Heyrovsky and Ilkovic.

The laws controlling the amount of current are interesting, and the amounts of variation can be figured without extra trials by the Ilkovic Equation[6] which, when stated without the Greek letters, means that the current registered is proportional to the concentration, times the valence change of the substance being reduced, times the Faraday constant, times the diffusion coefficient to the $\frac{1}{2}$ power, times the mass of mercury flowing per second to the $\frac{2}{3}$ power, times the drop time to the $\frac{1}{6}$ power. This assumes a uniformity of temperature.

It is interesting to note that the current also varies as the square root of the pressure of the mercury column in centimeters of mercury, after slight correction for the back pressure of the drop itself. The height of curve is proportional to the valence change and inversely to the atomic weight of the element. Between one element and another, the migration of the ions is a factor; the heavier ions travel more slowly, but there is variation also among similar weights of ions.

The rise in temperature raises the heights of curves greatly and should be controlled very closely. It is also interesting that the dropping time is more rapid with an increasing voltage and that different electrolytes will also vary it. The rate of diffusion of the amalgam formed at the cathode and its back electromotive force (E.M.F.) is also a factor in determining the height of curves. Temperature control is important but, as for the rest, known standard solutions closely resembling the unknowns, and the use of uniform conditions all around, with a comparison of results, make one almost independent of formulas if empirical methods are preferred to calculations by formula. Trial in comparatively new methods is safer than formula.

As time goes on, true and tried formulas like the Ilkovic equation become increasingly safer to use. Also, interrelations of the values of the elements are becoming better known.

Various suppressants such as acid dyes and negative colloids suppress the positive maxima, whereas basic dyes and positive colloids suppress negative maxima.[7] Usually in analytical procedure the occurrence of maxima is a nuisance that can best be eliminated by addition of a suitable capillary-active ion.

Ordinary filter paper that has absorbed fumes from the city air acts on both sides of the polarographic zero. Many substances which are oxidized by air are best polarographed in closed vessels where the air has been expelled by a stream of hydrogen or nitrogen.

Other developments of the polarograph are the use of the oscillograph to get a photograph in a few seconds of the development of a single drop of mercury. This has been found practical in some cases.

In special work, a streaming electrode or even two balanced streaming electrodes are used. In this case, since there are no rise and fall intervals between falling drops of mercury, a smooth line is formed.

In the regular instrument, the galvanometer is damped so as to minimize the irregularities and to give an average current. A description of the technique is not warranted in this short report although the method

[6] Ilkovic, D., Collection Czechoslav. Chem. Commun., vol. 6, p. 498, 1934 . . . Jour. Chim. Phys., vol. 35, p. 129, 1938.

[7] Heyrovsky, J., Polarography, in Böttger, W., Die physikalschen Methoden der chemischen Analyse, vol. 2, pp. 260-332, Leipzig, 1936.

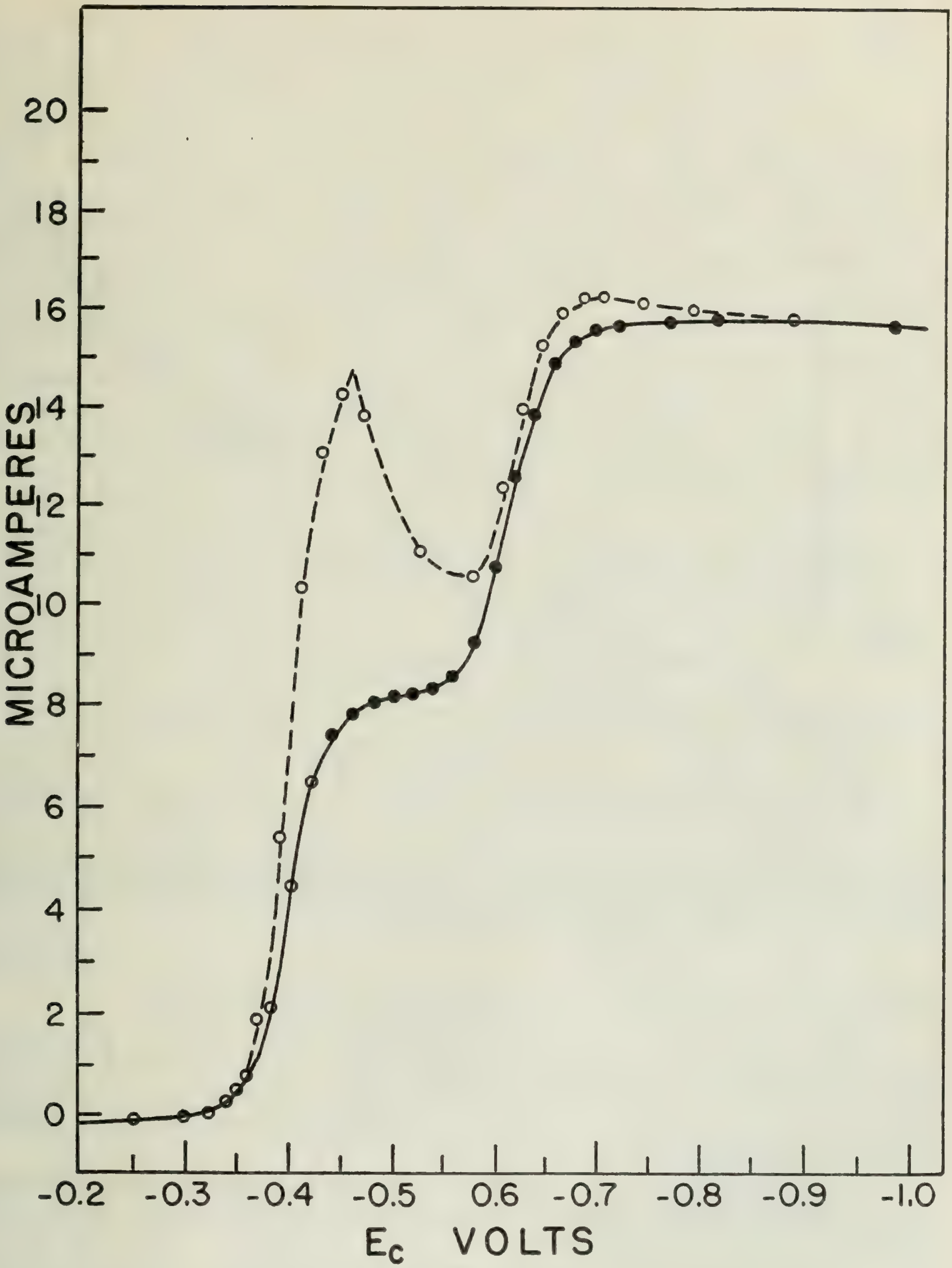

FIGURE 6. Diagram showing curves obtained with 0.001 molar lead and cadmium ions in 0.1 normal potassium chloride. Upper curve was obtained without a suppressor; the lower with 1 milliliter of 0.1 percent sodium methyl red added to 50 milliliters of the solution. *From Kolthoff and Lingane.*

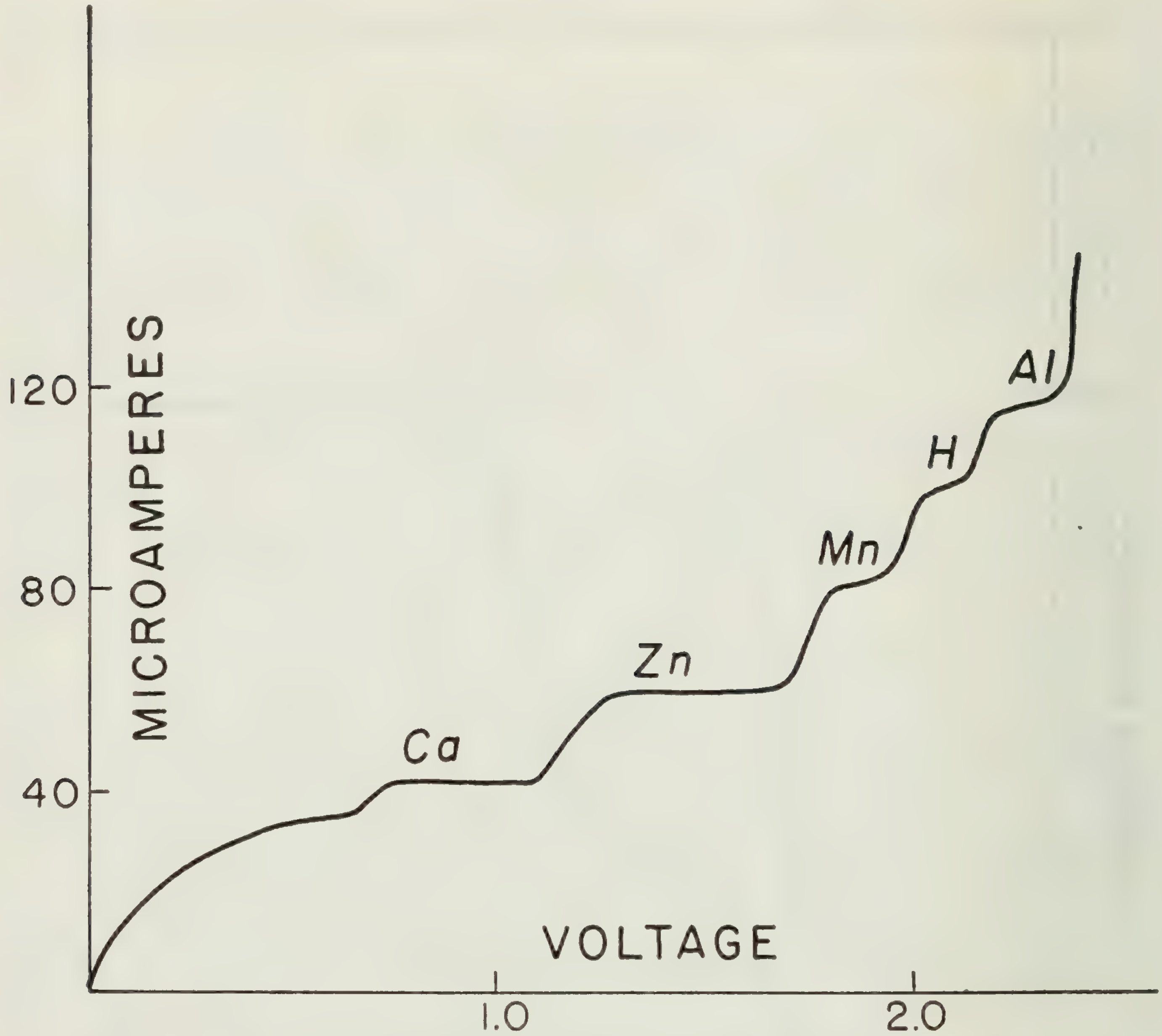

FIGURE 7. Stationary oscillogram obtained by Metheson and Nichols when the drop was 1/30 second and exactly synchronized with the 30-cycle linear voltage sweep; 0.0005 normal $CdCl_2$, 0.001 normal $ZnCl_2$, 0.001 normal $MnCl_2$, 0.0005 normal HCl_3, and 0.0005 normal $AlCl_3$ in 0.1 normal LiCl. *From Kolthoff and Lingane.*

is extremely sensitive to minute amounts of the ions sought. The curves are as much as 100 times as great as with the falling drop.

The spectrograph and polarograph have been used to determine trace elements in vegetable and animal matter [8], not only in the study of plants and animals, but also as a means of prospecting. The presence or absence of many metals in the soil is reflected in the growth of both plants and animals.

The absence of any one of the essential trace elements causes certain diseases in plants and animals; a great excess of almost any element is also likely to be damaging.

An analysis of plant ash by either polarograph or spectrograph is often enlightening. Certain trees which tolerate a great deal of zinc will grow in localities where other plants die. Localities where metallic mines are located have considerable amounts of the metallic elements in the plant and animal growth of the region, and limits of the mining district can often be determined by the smaller amount or absence of the same elements. Use of the instrument to locate mining areas and their limits will undoubtedly increase in the future.

[8] Stiles, Walter, Trace elements in plants and animals, New York, The Macmillian Company, 1946.

Lack of manganese causes gray speck in oats and heart rot in sugar beets. Peas, tung trees, barley maize, and sugar cane are also affected. Bow legs in chickens indicate a deficiency in manganese. Absence of zinc affects fruit trees, maize, tomato, squash, and buckwheat. The absence of boron will affect beans, tomatoes, citrus, potato, tobacco, maize, sugar beet, carrot, apple, radish, sunflower, squash, beet, and cabbage. A large excess of boron will kill most plants. An absence of boron was the chief cause of the potato blight in Ireland, although evidence has been found that potatoes need silver, and this may have been a contributing cause.

Copper is a necessity for possibly all plants and animals. In cases of lead poisoning, copper is an aid in causing the precipitation of lead in the stomachs of animals. In the malady called ''salt disease,'' copper was a great aid; but it was found that too much lead was the real cause. When sheep and cattle have ''swayback,'' it is well to look for lead in the district. It has been found that ''alkali disease'' is due to selenium. If sufficient selenium could be obtained, it could be substituted for sulphur in rubber tires that would outlast the automobile. Excessive molybdenum causes the disease known as ''scouring,'' which is cured by copper sulphate. Clover may take up over 150 parts of molybdenum per million of dry clover. Cobalt deficiency causes ''pining'' (Morton Main disease) in sheep and cattle. Dosages containing 10 milligrams in 2 weeks cure it. Cobalt causes uptake of molybdenum, which is prevented by acid. Cobalt is a necessity for animal life but not for plant life.

The following section on electrodeposition of gold, illustrates several new facts, for instance that the order of addition of an inorganic substance makes a difference in the compound formed. It illustrates maxima, various details of standard procedure, new methods of procedure, and furnishes information about gold, the metal which has been of the first importance to prospectors. Later development of the method described therein completely annihilates the fairy tales of ''gold that can not be assayed by fire,'' as the polarograph closely checks the standard methods.

THE ELECTRODEPOSITION OF GOLD[9]

Until recently it was thought that gold, being nobler than mercury, could not be determined polarographically from its solutions by means of the dropping mercury kathode.

The only way open to electrochemical investigations was to find suitable complexes from which gold could not be deposited on the mercury electrodes without the application of external electromotive force. This was indeed attempted by E. B. Sanigar,[10] who used a solution of $KAu(CN)_4$ in a solution of KNO_3 and obtained a curve showing a decomposition voltage of about 0.3.

In this work, solutions containing various complexes of gold were investigated first, from which the cyanide solutions were found to be the most suitable for analytical purposes, although the alkali hydroxide complexes were the first to give satisfactory curves.

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[9] Reprinted from Polarographic studies with the dropping mercury kathode, pt. 37, Collection 6, nos. 1-2, Des travaux chimiques de Tchécoslovquie, 1934.

[10] Rec. travaux chim., tome 44, p. 574, 1925.

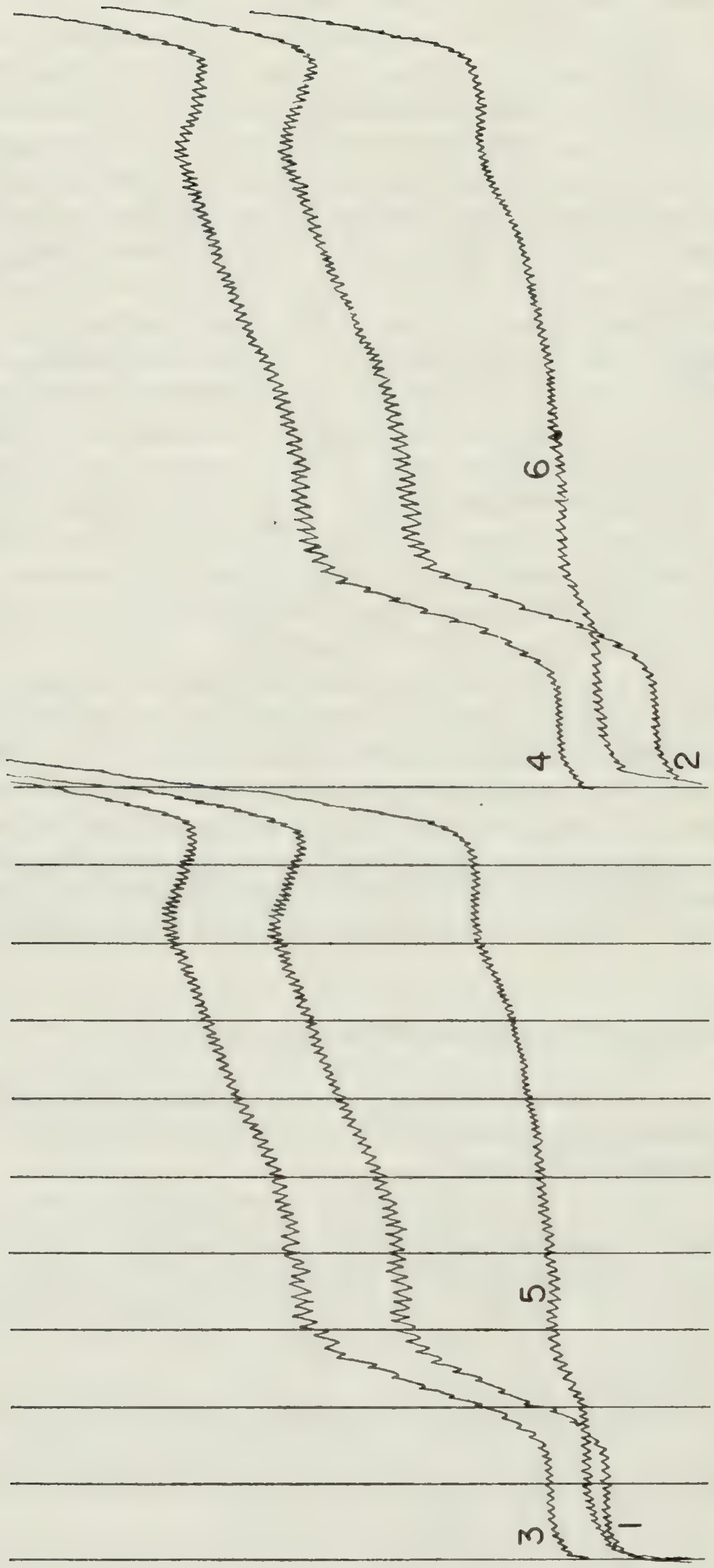

FIGURE 8. To 10 cubic centimeters of 2 normal KOH, 2.5 cubic centimeters of about 0.01 molar $AuCl_3$ was added, open to the air (separate anode), 4 volts accumulative. Curve 1 obtained just after mixing; curve 2 repeated after 5 minutes; curve 3, 5 minutes after curve 2; curve 4, 5 minutes after curve 3; curve 5, after shaking mercury with the solution. Sensitivity = 1/100.

Choice of Suitable Complexes

In order to avoid deposition of gold on the mercury, the solution must contain a complex of gold which is considerably more stable than the corresponding mercury complex. Unfortunately nearly all complexes of gold are similar to those of mercury and, therefore, from them the mercury precipitates metallic gold. The following were found to be decomposable complexes: $NaAuCl_4$ and analogous salts, complexes with Na_2SO_4, H_2SO_4 (prepared from the $Au(OH)_3$), Na_2HPO_4, $NaHCO_3$, Na_2CO_3; all very rapidly form a deposit on the mercury surface, either black, red, or brown. The polarographic curves are not reproducible in such cases, as the concentration of gold rapidly diminishes and the surfaces of both electrodes change.

The next class of gold complexes consists of those which are stable enough to give reproducible curves, yet show a gradual decrease of gold content, owing to slow decomposition in presence of mercury. Such were found to be Na_2SO_3 in great excess over $HAuCl_4$; similarly, KCNS or NH_4CNS in excess; Na_2S or K_2S in excess; and the most stable of this class, complexes in KOH or NaOH.

The hydroxide complex indeed is a remarkable one, as it shows a decomposition voltage, whereas all the other substances mentioned start electrolytic decomposition at the very beginning of the applied electromotive force. However, the analysis of mercury which has stood some 24 hours in contact with the alkaline gold solution shows some 10 percent decomposition of the alkaline gold solution. Owing to this relative stability, the hydroxide complex has been investigated in detail.

The Gold Complexes in Alkali Hydroxide Solutions

The chemical character of the hydroxide of gold would lead us to expect an entirely different type of complexes from mercury, whose hydroxide is not amphoteric. On the other hand, both auric and aurous hydroxides dissolve in alkaline solutions readily enough to form solutions which can be conveniently tested for gold polarographically.

The typical curve shown in figure 8 (repeated) is obtained when a solution of auric chloride is added to 2 normal KOH. The lowest curve in figure 8 shows how the gold disappears from the solution when the solution is shaken with mercury. The increase of current shown on this curve at the beginning of the polarising electromotive force is due to the saturation of the KOH solution with mercuric oxide; the later increase is probably caused by impurities in the strong alkali plus some aurous complex.

This polarogram also shows the characteristic change which the current-voltage curves of alkali hydroxide solutions containing auric chloride undergo with time. Curve 1, which was obtained shortly after mixing the gold solution with the KOH, shows at the very beginning of the polarising electromotive force a steep increase indicating the deposition of gold from a very loose complex, if not from free ions. When repeated after 5 minutes (curve 2), this initial increase is much smaller; it diminishes further when 5 more minutes have passed (curve 3), and nearly disappears in another 5 minutes (curve 4). This polarogram was obtained without eliminating oxygen from the solution, yet with a separate anode to limit the deposition of gold by mercury.[11] Many curves

[11] Electrode vessel and arrangement similar to that used by P. Herasymenko and I. Slendyk, Collection, 4, 333 (1932).

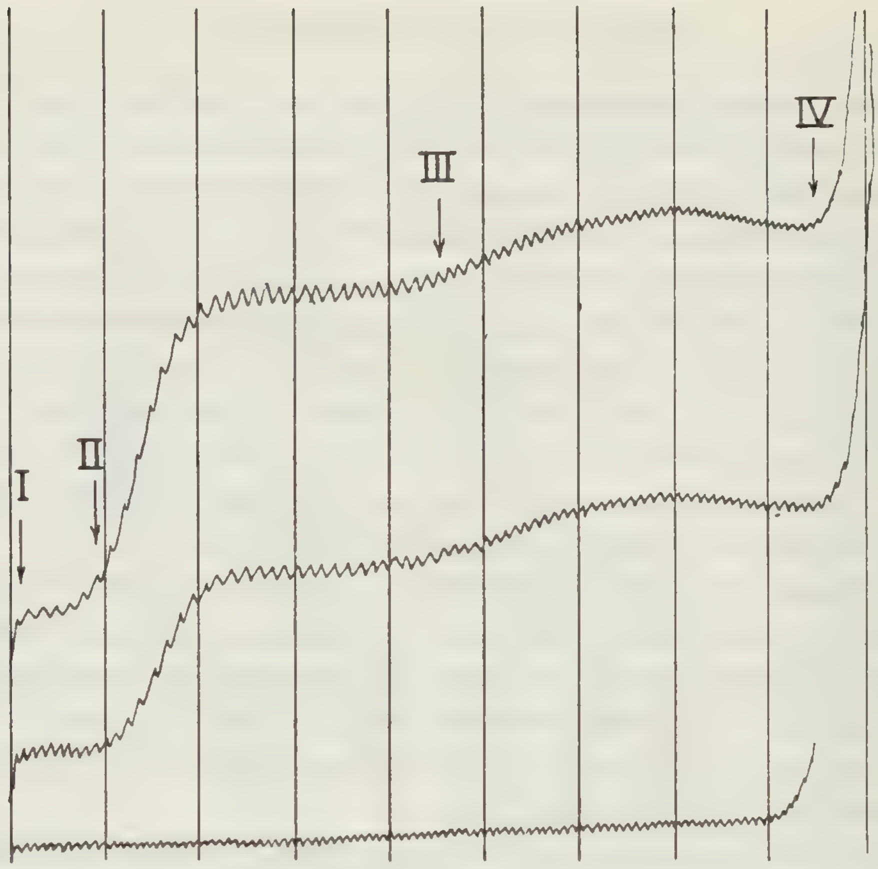

FIGURE 9. To 10 cubic centimeters of 2 normal KOH (lowest curve), 1 cubic centimeter (middle curve), and 2 cubic centimeters (upper curve) of 0.02 molar $AuCl_3$ was added, in hydrogen atmosphere, 4 volts accumulative. Sensitivity = 1/100.

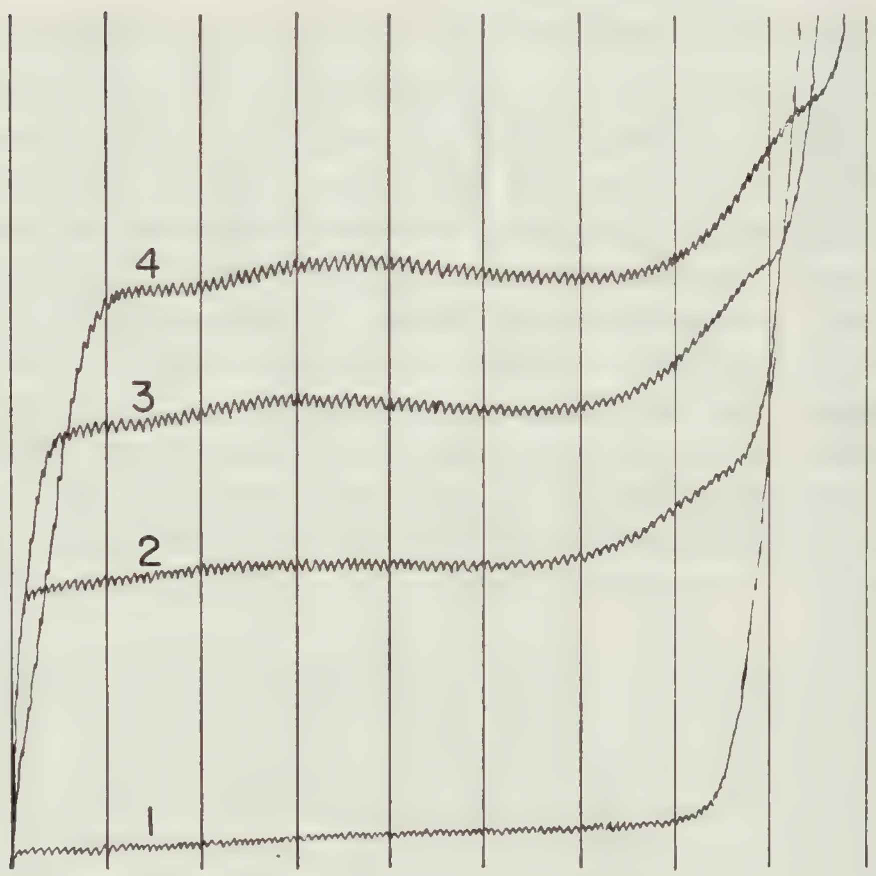

FIGURE 10. To 10 cubic centimeters of 0.01 normal KCN, a 0.01 molar $NaAuCl_4$ solution was added. Curve 1 obtained with pure 0.01 normal KCN in hydrogen atmosphere; curve 2, 0.8 cubic centimeters, curve 3, 1.4 cubic centimeters, curve 4, 2.0 cubic centimeters gold solution added. Sensitivity = 3/100.

have been obtained with the oxygen removed from the solution by bubbling either pure hydrogen or nitrogen especially freed from traces of oxygen.

In this manner the true shapes of current-voltage curves due only to gold are obtained. In these experiments even the gold solution added from a burette was freed from oxygen and the mixing was carried out in an atmosphere of nitrogen or hydrogen. Figure 9 shows typical curves due to different amounts of auric chloride added to 2 normal KOH. Here we notice: (1) the first increase at zero voltage ascribed, as explained above, to a very loose complex of gold, if not free ions; (2) a second increase at 0.2 volt of applied electromotive force (that is, at a kathodic potential of —0.4 volt from the normal calomel electrode), the nature of which will be discussed below; (3) a third increase of current at about 0.9 volts of electromotive force (that is, at —1.1 volts from the normal calomel electrode) less steep and less prominent than the second one; (4) the fourth, very steep increase at 1.7 volts of electromotive force (that is, at —1.9 volts from the normal calomel electrode), which is evidently due to the deposition of potassium ions.

It has been found that, if alkaline solutions containing auric chloride have been standing, or heated, the second wave diminishes, becoming transformed into the third wave; eventually even the third wave diminishes by deposition of gold and gold hydroxide (probably aurous). The second increase of current (at —0.4 volt) is ascribed to the electrodeposition of gold from the trivalent form, and the third increase (at —1.1 volt) to the electrodeposition of gold from the monovalent complex.

It was thought possible that one of the waves might be due to the presence of hydrogen peroxide which could be formed in such solutions in accordance with the equilibrium of the reaction: $Au(OH)_{-4} = Au(OH)_{-2} + H_2O_2$.

To test this, a weak solution of hydrogen peroxide was added to an alkaline gold solution, but this addition did not produce any of the waves coinciding with the three waves described above.

The influence of the increase of concentration of hydroxyl ions has no decided effect on the total height of the curve, except with the passage of time, when the second wave (due to trivalent gold) sinks a certain amount, while the third wave (due to monovalent gold) rises one third of that amount. As a consequence of this gradual reduction in strong alkaline solution (five times normal), we find the third wave better developed than in dilute alkaline solution.

It was found when mixing together KOH, KCN, and gold solutions, that the curves depend on the order of mixing.

The Gold Complexes in Cyanide Solutions

There are two distinct complexes of gold with cyanide solutions, namely, trivalent and monovalent gold. In this investigation, the trivalent complexes were always prepared from solutions of trivalent gold ($HAuCl_4$ and $NaAuCl_4$) with an excess of KCN or other soluble cyanides.

Curves obtained in typical trivalent cyanide solutions are shown in figure 10. There is a very steep increase starting from zero voltage, which is then followed by a limiting current until a voltage of about 1.4, where a small increase is followed by the deposition of potassium ions. This polarogram was obtained by adding increasing quantities of auric chloride to centinormal potassium cyanide. The amount of gold in the last

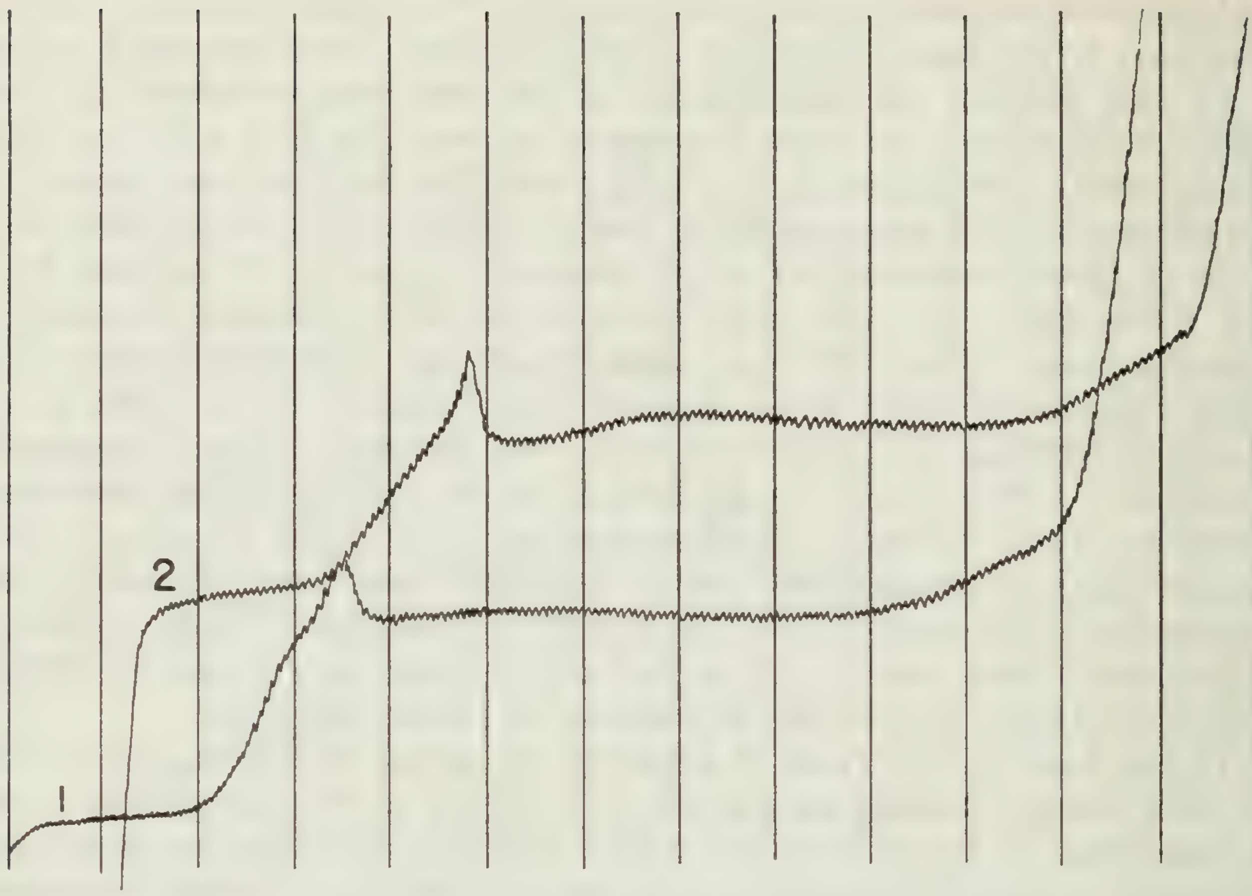

FIGURE 11. To 0.01 normal KCN an approximately equivalent amount of 0.01 molar $AuCl_3$ was added. Sensitivity = 1/100.

curve was approximately $\frac{1}{600}$ molar. The limiting current increases in direct proportion to the concentration of gold; further, the second wave starts at more positive potentials when the concentration of cyanide is increased, so that in a 0.1 normal solution of potassium cyanide it appears at about 0.8 of a volt, whilst the first wave always starts at the very beginning (see fig. 14). This first sudden increase of current led to the suspicion that there was a deposition of gold on mercury without any external electromotive force applied. Yet accurate analysis showed that this was not the case. Indeed, no solution of trivalent or monovalent gold cyanide was found to deposit any gold in contact with mercury.

If more auric chloride is added to a weak solution of alkali cyanide, the current-voltage curves acquire the shape shown in figure 11. When exact equivalency is reached between KCN and $NaAuCl_4$, curve 1 is obtained, in which a decomposition voltage of about 0.4 is plainly visible. This is no doubt due to the fact that in the reaction

$$NaAuCl_4 + 3KCN = NaCl + 3KCl + Au(CN)_3$$

the cyanide ions have entirely disappeared and consequently the anode potential has become considerably more positive. The curve is therefore similar to that obtained by Sanigar. The decomposition voltage of 0.4 is needed to deposit gold from the complex trivalent cyanide in the absence of excess of cyanide ions. This behavior indicates that if alkali cyanide is added and the anode potential becomes consequently much more negative, the kathodic potential at which the trivalent complex decomposes will be placed at the very beginning of the curve. Therefore the first increase of current in complex cyanide solutions of gold is ascribed to the deposition of gold from the trivalent complex. It might be thought that this increase of current is due to a reduction of trivalent gold to the monovalent stage. However, then the second wave, which is

undoubtedly due to the deposition from the monovalent gold (as is evident from solutions containing entirely monovalent complex gold cyanide), should be at least half as high as the first wave. This has never been found to be the case in fresh solutions of trivalent gold complexes, the second wave always being smaller than half of the first. The experience of numerous polarographic trials shows indeed that the electroreduction process of the first increase of current is entirely independent of what happens at the second increase of current.

If an excess of auric chloride over cyanide is added (see curve 2), there is a new sudden increase of current at zero voltage and at the same time the mercury in contact with the solution becomes coated with metallic gold. The sudden increase in curve 2 (fig. 11) is therefore ascribed to the deposition of gold from its free trivalent ions. If these ions were in perfectly mobile equilibrium with the complex trivalent ions, only one decomposition voltage should be observed, at which the trivalent gold would be deposited. However, the almost independent existence of the two waves shows that no such mobile equilibrium exists between the free and the complex trivalent gold ions.

It is evident from this polarographic study that the changes of ionic forms of gold in solution take place with extreme slowness, so that equilibrium is practically not attainable.

For the study of the monovalent gold complex, the solutions were prepared by two general methods: first, by the action of KCN on metallic gold; second, by the reduction of trivalent gold either by the iodide method, with the subsequent removal of free iodine by Na_2SO_3 and then added KCN and enough KOH to neutralize the SO_2 formed, or by Na_2SO_3 alone and then KCN and KOH added. All these solutions give curves showing one wave at the decomposition voltage of about 0.8.

Figure 12 shows the accumulation of monovalent gold cyanide in a decinormal solution of KCN due to the gradual solution of gold foil. This allows the gold cyanide solutions to be analyzed by simply measuring the height of the wave, when ascribing it all to monovalent gold. In this manner it is found that with a concentration of 10^{-4} molar aurous complex a 2.6-centimeter wave is obtained when the sensitivity of the galvanometer equals 10^{-8}. A direct comparison of an equivalent amount of gold, silver, and cobalt shows that their equimolar solutions give approximately the same height wave.

More distinct bends on the current-voltage curves than those shown in figure 12 are obtained when these solutions are filtered. The polarogram figure 13 shows this effect. The flattening within the first 0.8 of a volt is due to the absence of oxygen which must have been consumed in a peculiar oxidation process taking place in the filter paper. The limiting current is also more flattened, showing no tendency to form a maximum. This allows more exact measurement of the quantity determined from the height of the wave. It was thought that the loss of height of the wave, which appears after filtration, might be due to the adsorption of gold in the filter paper if not actual reduction to metallic gold. However, the thoroughly washed filter paper showed no gold, and direct comparison of repeatedly filtered gold solutions revealed adsorption only to a minute extent, as shown by the superposition of curves obtained after each filtration.

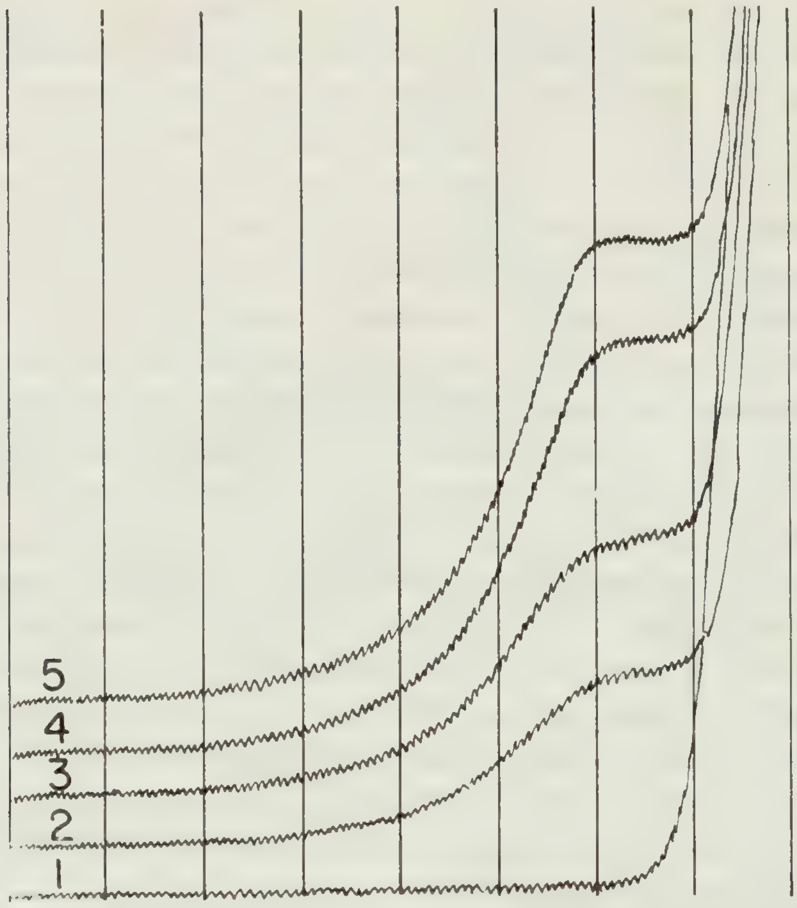

FIGURE 12. Curve 1 was obtained in pure 0.1 normal KCN; curve 2, when gold foil had been 2 hours in contact with KCN solution; curve 3, 4 hours; curve 4, 6 hours; curve 5, 8 hours. All in hydrogen atmosphere. Sensitivity = 3/100.

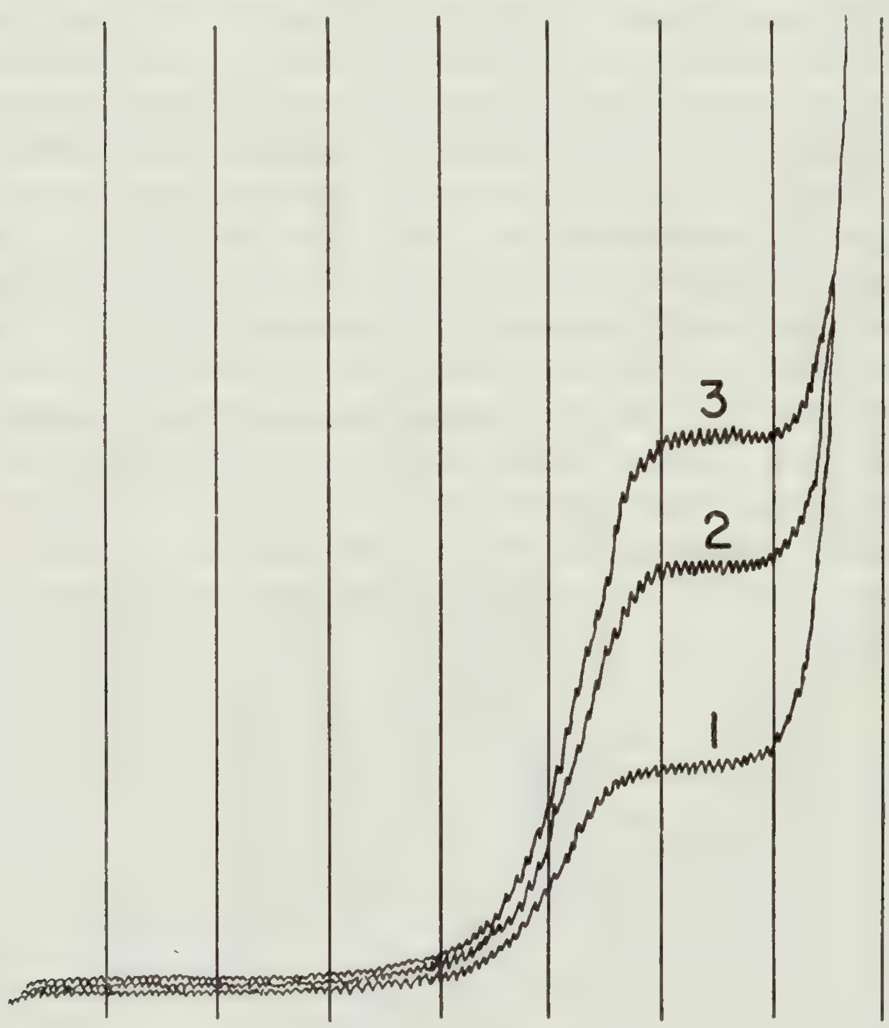

FIGURE 13. To 10 cubic centimeters of 0.1 normal KCN solution were added: for curve 1, 2 cubic centimeters of gold cyanide solution; for curve 2, 4 cubic centimeters of gold cyanide solution; for curve 3, 5.5 cubic centimeters of gold cyanide solution. Solutions were electrolyzed open to the air, after filtration. Sensitivity = 1/100.

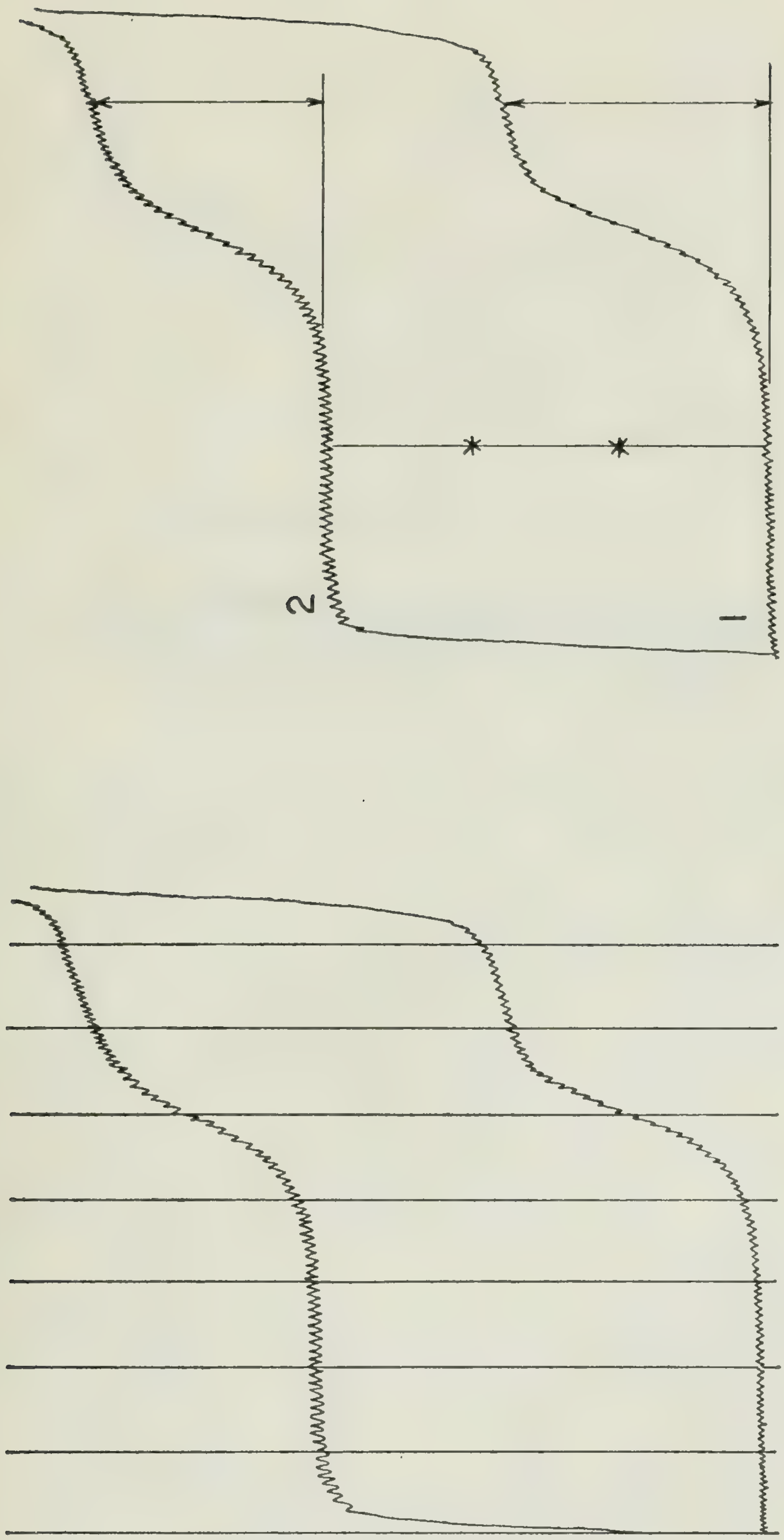

FIGURE 14. Lower curves were obtained with 0.009 molar AuCN in 0.1 normal KCN; upper curves with 0.01 molar $Au(CN)_3$ in 0.1 normal KCN; solutions were electrolyzed in open air, after filtration. Sensitivity = 1/100.

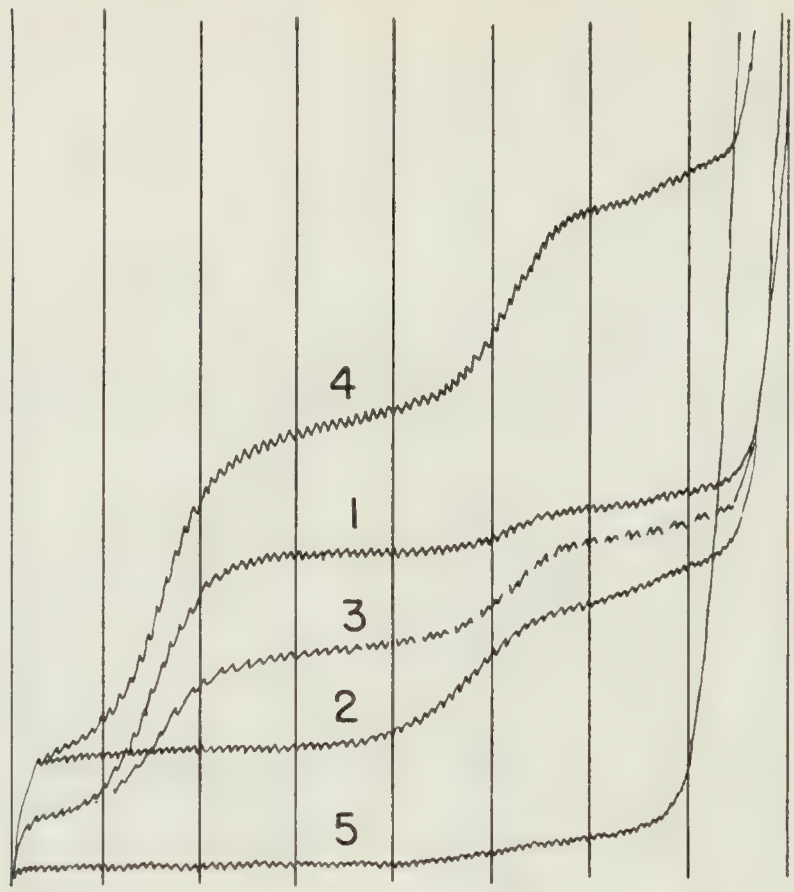

FIGURE 15. Solutions containing components mixed in different order. Electrolyzed in open air, after filtration. Sensitivity = 1/100, except in top curve, where it was 2/100.

FIGURE 16. Electrolyzed open to the air

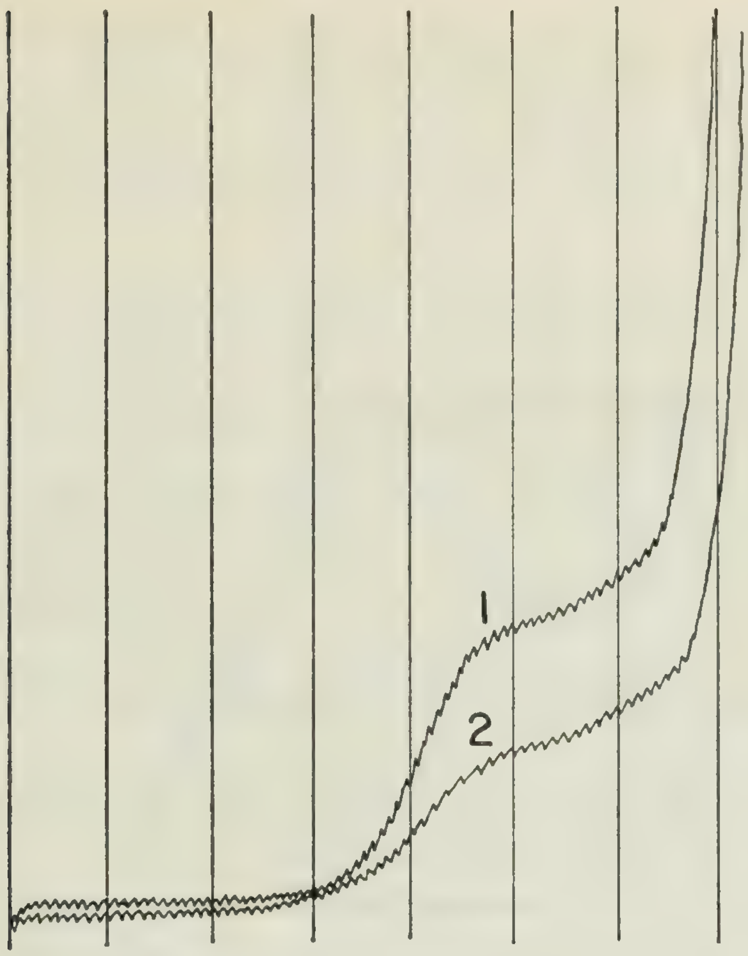

FIGURE 17. A solution of 0.005 molar AuCN in 0.1 normal KCN, 2 normal KOH, obtained by adding KI to $AuCl_3$, then Na_2SO_3, then solutions of KCN, KOH. Electrolyzed open to the air, after filtration.

The curves shown in figure 14 were obtained after filtration. They represent the difference between two solutions, one of which contained the trivalent and the monovalent complex, and the other only the monovalent complex in nearly the same molar concentration. (The monovalent complex is about 90 percent as strong as the other.) According to the Faraday law, the electro-deposition of one mol of the trivalent complex requires three times as much current as the deposition of one mol of the monovalent complex. Therefore the total increase of current on curve 1 should be equal to the sum of one third of the first rise of curve 2 plus the full height of the second rise of curve 2. This, however, corresponds closely to observed data, although some difference must be due to the different speeds of diffusion of the two complexes.

Having thus ascertained that a quantitative analysis of the trivalent and monovalent complexes is possible, we are enabled to follow changes of valence which take place in solutions of complex cyanides. We observe that the first increase of current slowly diminishes while the second slightly increases. This, of course, means that with time the trivalent complex is converted into the monovalent; the speed of this reduction has been found polarographically to increase with the concentration of the alkali cyanide, of hydroxyl ions, and with temperature, so that eventually the curve typical for the monovalent complex is obtained.

A pronounced influence has been observed on current-voltage curves of some cations, when present in larger amounts in the cyanide solution. Thus gold solutions made up in lithium, sodium, and barium cyanide yield curves which show waves with indistinct bends, and the current begins to rise at a more positive potential. On the other hand, the

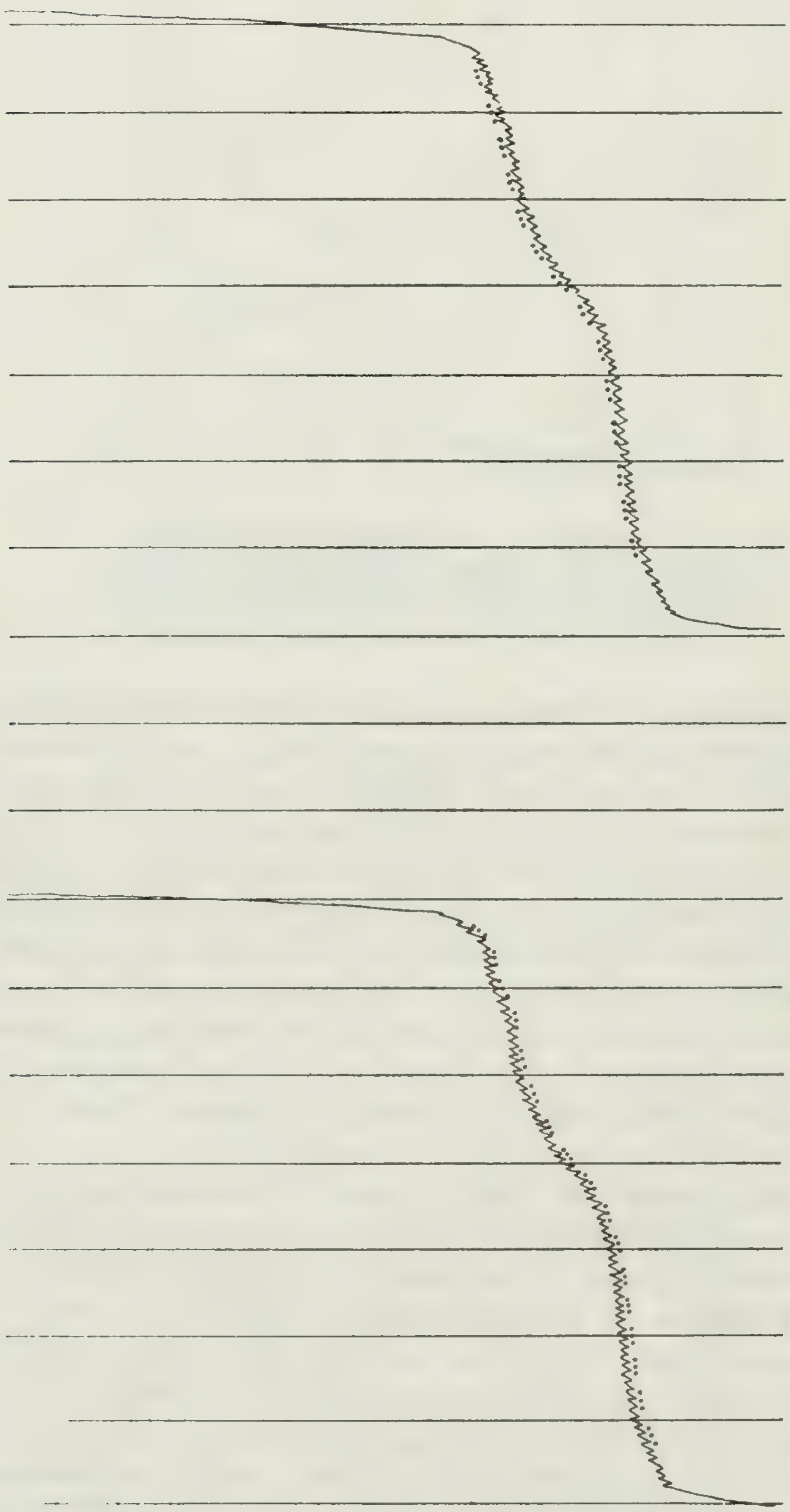

FIGURE 18. Approximately 0.005 molar gold solution electrolyzed open to the air, after filtration.
Sensitivity = 1/100

addition of KCl to NaCN made the curve look like a typical KCN curve with sharp bend and distinct wave formation. As in the case of alkali hydroxide complexes, it was ascertained that the bends observable on curves in cyanide-gold solutions are not due to hydrogen peroxide or to cyanates.

The Gold Complexes in Mixtures of Alkali Cyanide and Hydroxide Solutions

As already mentioned, a strange behavior was encountered when investigating mixtures of alkali hydroxide and alkali cyanide complexes. It was found that the shape of the curve of the alkali hydroxide gold complex is maintained after cyanide has been added; also that the typical curve of the complex gold cyanide remains unchanged after alkali hydroxide has been added.

This is illustrated by the polarogram figure 15. All these curves are due to solutions of identical composition, in which, however, the components were mixed in different order. All contain 0.1 normal KCN, 2 normal KOH and 0.02 molar trivalent gold. In curve 1, $NaAuCl_4$ was added first to KOH and then KCN admixed. In curve 2 $NaAuCl_4$ was added first to KCN and then KOH admixed. In curve 3 the solutions of curves 1 and 2 were mixed in equal proportion. Curve 4 was obtained by doubling the sensitivity of curve 3. Curve 5 is the blank KCN + KOH without gold. We see that curve 1 resembles that of the KOH complex, showing the three increases described among the alkali hydroxide curves. Curve 2 is typical for the KCN complex, showing the two waves due to the trivalent and monovalent gold cyanide complexes. Curve 3 is midway between curves 1 and 2, thus demonstrating that in the mixture each complex keeps its individuality. A curve of this solution was taken with doubled sensitivity (curve 4) to show that the current is an addition of the ordinates of curves 1 and 2. (The additivity is, however, incomplete within the first 300 millivolts, because the time effect of decomposition is shown mostly in the first portion of the curve).

Therefore, to the two foregoing rules we may add, that if a solution giving a gold-cyanide type curve is mixed with a solution giving a gold-hydroxide type curve, the curve of the mixture is an arithmetic mean of the two current-voltage diagrams. Finally a fourth rule has been found to hold, that if to a mixture of alkaline hydroxide and alkaline cyanide a solution of gold chloride is added, only the cyanide curve is shown.

Maxima Resulting from Aurous Cyanide Complexes

From the various curves obtained during the investigation, some conspicuous maxima appeared, especially in solutions containing the monovalent cyanide complex. These were found to be promoted by a strong concentration of hydroxyl ions and suppressed by dilution or by filtration. The peculiarity of the dilution was that once the solution was suppressed the maximum could never be obtained again in the original height by bringing back the original strength of the solution. Moreover, time alone was a factor in suppressing the maximum. The lower limit of the KOH concentration at which maxima appear of the monovalent KCN complex is about 1 normal KOH.

When trivalent solutions are used, the maximum appears only on the wave which is ascribed to the reduction of the monovalent complex.

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Figure 16 illustrates this behavior. Here curve 1 was obtained by adding gold chloride to a solution of 2 normal KOH and normal KCN; it shows a prominent maximum. Curve 2 resulted when the solution was made up by diluting solution 1 with an equal volume of water. Curve 3 was obtained from solution 2 after filtration.

Analytical Procedure

In order to estimate polarographically the gold in ores, bullion, etc., it is possible to use several methods. Gold, even in tellurides, can be dissolved by the action of iodine in potassium iodide solution, and in many cases directly by cyanide or by aqua regia or chlorine.

The polarographic analysis of cyanide solutions has been sufficiently discussed to arrive at the conclusion that quantitative analysis is possible. In large concentrations of KCN, zinc, copper, and iron are not shown polarographically, while silver, arsenic, antimony, lead, and bismuth do not interfere. The gold can also be precipitated with zinc and suitably separated to prepare the solution for polarographic determination.

The iodine method has already been described. An example of a similar analysis is given in figure 17. Here potassium iodide was added to the gold solution, the iodine reduced with Na_2SO_3, cyanide and KOH added, and the solution filtered; then it was electrolyzed with the polarographic arrangement.

An innovation has been introduced for exact quantitative measurements in cases where very small differences in concentration are to be considered. It consists in placing the curve of a standard solution on the same beginning as the curve of the solution being measured. For one of the curves the reflected beam of light coming from the galvanometer is slowly interrupted. This makes a series of dashes as shown in fig. 18. A difference of about 0.1 millimeter in the height of waves is thus clearly seen.

The changes registered in fig. 18 are those due to the slow decomposition of the trivalent gold cyanide complex into the monovalent gold cyanide complex. The order in which the curves were registered is: first, left, full curve, then right, interrupted curve, then left, interrupted curve, and finally, right, full curve. Therefore the dotted line is about as high above the full line on the right as the dotted line is below the full line on the left. The time that elapsed between two successive curves was 4 minutes.

Finally, it should be pointed out that this experimental investigation is based on the examination of 230 polarograms with about 1600 curves.

Discussion of Results

The outstanding phenomenon of theoretical importance encountered in this work seems to be the extreme steadiness of the gold complexes, chiefly of the trivalent gold in the mixture of alkali hydroxide plus cyanide, and the trivalent gold in cyanide. Once these complexes are formed by the addition of auric chloride either to the excess of the alkali hydroxide or to the excess of the alkali cyanide, they do not, as the type of current-voltage curve shows, interchange by the presence of the other complex-forming salts.

To understand what happens at the various stages of electro-reduction in the gold cyanide and hydroxide mixture, let us compute the values

of the observed deposition potentials. These potentials are derived from the decomposition voltage, as is shown on the curves, if it is subtracted from the mercury anode potential. The anode potential in approximately 2 normal KOH is —0.2 of a volt (from the normal calomel zero) and in calomel 0.1 normal KCN it is —0.4 of a volt. Symbolizing the trivalent gold hydroxide complex by $Au(OH)_4'$ (that is, as a monobasic aurate), and the monovalent gold hydroxide complex by $Au(OH)_2'$ (that is, as a monobasic aurite), and analogously the gold cyanide complexes as $Au(CN)_4'$ and $Au(CN)_2'$, we may note the following electrode processes:

$$Au(OH)_4' + 3\,\theta \rightarrow Au + 4\,OH' \text{ at } -0.4 \text{ v}$$
$$Au(OH)_2' + 1\,\theta \rightarrow Au + 2\,OH' \text{ at } -1.1 \text{ v}$$
$$Au(CN)_4' + 3\,\theta \rightarrow Au + 4\,CN' \text{ at } -0.4 \text{ v}$$
$$Au(CN)_2' + 1\,\theta \rightarrow Au + 2\,CN' \text{ at } -1.3 \text{ v}$$

To these deposition potentials observed in the hydroxide-cyanide mixture there should be added

$$[Au(OH')_x\,(CN')_y]^{(x+y-3)'} + 3\,\theta \rightarrow Au + xOH' + yCN'$$

at —0.8 of a volt.

This auric-hydroxide-cyanide complex is thus decomposable at a potential by about 0.4 of a volt more negative than the pure auric-hydroxide complex. Its stability accounts for the lack of interchangeability shown in a large excess of cyanide ions. On the other hand, a similar steadiness has to be ascribed to the pure auric-cyanide complex, since it is not transformable into the hydroxide complex.

The hydroxide or cyanide ions, if once bound directly to the Au^{+++} ion, are, owing to their deformability, so strongly held in the inner sphere of coordination, that other ions cannot be substituted in their place.

The transformation of the auric-hyroxide-cyanide complex into the cyanide complex, or vice versa, must be thus an extremely slow one. Here the observed fact is significant, that the trivalent gold complex in alkali hydroxide solutions is little affected by a subsequent addition of an alkali cyanide, since it continues to deposit gold on metallic mercury, although from gold cyanide complexes this deposition can never take place. The inertness of once-formed auric complexes in hydroxides or cyanides is shown also in the fact that they are not reduced by Na_2SO_3.

The aurous-hydroxide complex, however, appears to be completely transformable into the pure cyanide complex, as is evident from identical curves obtained by adding to a solution containing the aurous-chloride-sulphite-complex first KOH and afterwards KCN, or in the reverse order. The bends due to the electro-deposition of gold appear at the same potential, which is by about 0.3 of a volt more negative than that at which gold deposits from the pure aurous-hydroxide complex in 2 normal KOH.

There are also observable signs of slowness of the formation of gold complexes from current-voltage curves when auric chloride is added to a solution of alkali hydroxide. As has been mentioned about 8 minutes after the solutions have been mixed, gold deposits at zero voltage, causing a steep wave which rapidly diminishes with time, thus indicating that the easily reducible particles slowly become more complex.

This slowness of the adjustment to the conditions in the solution, exhibited in such a marked degree with the gold complexes, resembles the slow equilibrium attainment shown in complex zinc cyanide solutions, as

investigated by I. Pines.[12] There are, however, two significant differences between the formation of the complexes of gold and those of zinc.

Zinc deposits from alkali cyanide solutions at three different kathodic potentials, thus showing that the reducible complexes are not in perfectly mobile equilibrium; yet changes of the concentration of alkali cyanides cause pronounced differences in the curves, proving that in a comparatively short time a new equilibrium is established. Excess of alkali cyanide produces quickly a complex of zinc cyanide, so stable that its decomposition voltage cannot be reached polarographically.

Gold complexes, on the other hand, do not show any pronounced changes toward equilibrium when excess of alkali cyanide or hydroxide is added, but appear rigid, not transformable, after they have once been formed. The gold complexes, further, always remain electrolytically reducible, no matter what excess of the complex-forming anions be present. The peculiar rigidity of gold complexes, which, when once formed do not tend to enter into equilibrium with their components in the solution, indeed resembles the behavior of cobaltamines.

Auric cyanide complexes show the peculiarity that they are reducible at a smaller voltage, that is, more easily than the aurous complexes. From this we infer that auric hydroxide complexes will behave similarly and therefore ascribed the wave at —0.4 of a volt to the reduction of trivalent gold. The wave, observed in alkaline solution at —1.1 volts is therefore like one which is due to the reduction of the aurous hydroxide complex. That this reasoning was right has been proved by preparing aurous iodide and dissolving it in excess of alkali hydroxide. Indeed only an increase of current at about —1.1 volts appeared, that is, the "aurous wave."

The author wishes to express his thanks to Professor J. Heyrovsky for his constructive criticism and kind help.

Received, February 1934.

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SUMMARY

The electro-deposition of gold at the dropping mercury kathode has been investigated polarographically in solutions containing auric and aurous complexes with excess of alkali hydroxides or alkali cyanides.

From the auric complexes gold deposits at a voltage by 0.7 of a volt less than from the aurous complexes. The limiting current (height of wave) due to the electro-deposition of gold from aurous solutions is as high as that observed with silver solutions of equivalent strength.

It has been found that auric complexes are always accompanied by aurous complexes, into which they slowly decompose, but are in no mobile equilibrium.

The form of the current-voltage curves indicates that after the addition of KCN to the auric-hydroxide gold complex, an auric-hydroxide-cyanide complex is formed, which when once formed, remains unaltered even in the presence of a large excess of alkali cyanide. The auric-cyanide complex is, however, not transformable into the hydroxide-

[12] Collection 1, p. 429, 1929.

cyanide complex by excess of KOH. When mixed, both types of complexes keep their individual properties, and are therefore not interchangeable.

The author wishes to acknowledge with thanks the assistance of Messrs. McBurney and Jones of Smith Emery Company; also the permission granted by Dr. I. M. Kolthoff to use illustrations from *Polarography,* by Kolthoff and Lingane.

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PUBLIC RESOURCES CODE

An act to establish a Public Resources Code, thereby consolidating and revising the law relating to natural resources, the conservation, utilization, and supervision thereof, and matters incidental thereto, and to repeal certain acts and parts of acts specified herein.

Chapter 93 (Stats. 1939, with amendments to 1947)

The people of the State of California do enact as follows:

GENERAL PROVISIONS

1. This act shall be known as the Public Resources Code.

2. The provisions of this code, in so far as they are substantially the same as existing provisions relating to the same subject matter shall be construed as restatements and continuations thereof and not as new enactments.

3. All persons who, at the time this code goes into effect, hold office under any of the acts repealed by this code, which offices are continued by this code, continue to hold the same according to the former tenure thereof.

4. No action or proceeding commenced before this code takes effect, and no right accrued, is affected by the provisions of this code, but all procedure thereafter taken therein shall conform to the provisions of this code so far as possible.

5. Unless the context otherwise requires, the general provisions hereinafter set forth shall govern the construction of this code.

6. Division, part, chapter, article, and section headings contained herein shall not be deemed to govern, limit, modify or in any manner affect the scope, meaning, or intent of the provisions of any division, part, chapter, article, or section hereof.

7. Whenever, by the provisions of this code, an administrative power is granted to a public officer or a duty imposed upon such officer, the power may be exercised or the duty performed by a deputy of the officer or by a person authorized pursuant to law.

8. Writing includes any form of recorded message capable of comprehension by ordinary visual means. Whenever any notice, report, statement or record is required by this code, it shall be made in writing in the English language.

9. Whenever any reference is made to any portion of this code or of any other law of this State, such reference shall apply to all amendments and additions thereto now or hereafter made.

10. "Section" means a section of this code unless some other statute is specifically mentioned.

11. The present tense includes the past and future tenses; and the future the present.

12. The masculine gender includes the feminine and neuter.

13. The singular number includes the plural, and the plural the singular.

14. "County" includes "city and county."

15. "Shall" is mandatory and "may" is permissive.

16. "Oath" includes affirmation.

17. "Signature" or "subscription" includes mark when the signer or subscriber can not write, such signer's or subscriber's name being written near the mark by a witness who writes his own name near the signer's or subscriber's name; but a signature or subscription by mark can be acknowledged or can serve as a signature or subscription to a sworn statement only when two witnesses so sign their own names thereto.

18. If any provision of this code, or the application thereof to any person or circumstances, is held invalid the remainder of the code, and the application of its provisions to the other persons or circumstances, shall not be affected thereby.

DIVISION 1. THE DEPARTMENT OF NATURAL RESOURCES

501. There is in the State government a Director of Natural Resources. The department shall be conducted under the control of an executive officer known as Director of Natural Resources. The director shall be appointed by and hold office at the pleasure of the Governor and shall receive a salary of ten thousand dollars ($10,000) a year. (Amended by Stats. 1945, ch 1185, §10.)

502. Except as in this division otherwise provided, the provisions of Article 2, Chapter 3, Title 1, Part 3 of the Political Code shall govern and apply to the conduct of the Department of Natural Resources in every respect the same as if such provisions were herein set forth at length, and wherever in that article the term "head of the department" or similar designation occurs, it shall for the purposes of this division mean the Director of Natural Resources.

503. For the purposes of administration the department shall be organized by the director, subject to the approval of the Governor, in such manner as he deems necessary properly to segregate and conduct the work of the department. The director may appoint, in accordance with the civil service and other provisions of law, such deputies, officers, and other expert and clerical assistants as may be necessary.

504. The work of the department shall be divided into at least four divisions, known as Division of Forestry, the Division of Parks, the Division of Fish and Game, and the Division of Mines.

505. (1) There shall be a State Board of Forestry of seven members appointed by the Governor with the advice and consent of the Senate, except that the members of the board in office on the effective date of this section shall hold office for the terms herein provided.

One member shall represent the pine producing industry.
One member shall represent the redwood producing industry.
One member shall represent forest land ownership.
One member shall represent the range livestock industry.
One member shall represent agriculture.
One member shall represent the beneficial use of water.

The aforementioned six members shall be persons of practical knowledge and experience in the field they are to represent. One member shall be appointed from the general public at large.

The members now in office shall be classified by the Governor so that the term of one member shall expire on the fifteenth of January, 1946, and the terms of two members on January 15, 1947, 1948, and 1949, respectively. Each subsequent appointee shall hold office for four years from the expiration of the term of his predecessor and until his successor is appointed and qualified. An appointment to a vacancy occurring before the expiration of a term shall be but for the remainder of that term.

All appointments of members made when the Legislature is not in session shall be subject to confirmation by the Senate at the next regular or special session of the Legislature.

The board shall have power to organize itself and to select its officers.

(2) The board shall represent the State's interest in the acquisition and management of State forests as provided by law and in Federal land matters pertaining to forestry, and the protection of the State's interest in forest resources on private lands, and shall determine, establish, and maintain an adequate forest policy. General policies for guidance of the Division of Forestry shall be determined by the board.

(3) The board shall nominate and the Director of Natural Resources shall appoint a technically trained forester, in accordance with the State Civil Service Act, as the State Forester, who shall be Chief of the Division of Forestry in the Department of Natural Resources, and who shall administer the policies of the board under the supervision of the Director of Natural Resources.

The director may authorize the State Forester to exercise his power to appoint employees of the Division of Forestry in accordance with the State Civil Service Act. The director may authorize the State Forester or any employee of the Division of Forestry to exercise any power granted or perform any duty imposed upon the director by the State Civil Service Act. (Amended by Stats. 1945, ch. 316, §1.)

506. The Division of Parks shall be administered through a chief who shall have at least five years of executive experience in park, recreational, or related types of administration, and who shall be appointed by the director upon nomination by the State Park Commission. General policies for the administration, protection, and development of the State Park System shall be determined by the State Park Commission which shall consist of five members appointed by the Governor, with the advice and consent of the Senate.

The members of the State Park Commission shall be selected because of their interest in park and conservation matters and shall serve for terms of four years and until their successors are appointed and qualified. The Governor shall make the first appointments hereunder for terms expiring, respectively, on the fifteenth day of January, as follows: Two in the year 1947, two in the year 1948, and one in the year 1949.

The Governor shall specify, previous to July 1, 1946, a termination date of appointment, coincident with January 15th, for the members holding office at his pleasure.

In case of any vacancy the appointment shall be for the remainder of the unexpired term. All appointments of members made when the Legislature is not in session shall be subject to confirmation by the Senate at the next regular or special session of the Legislature (Amended by Stats. 1945, ch. 1438, §1.)

506.6. (1) The State Park Commission is hereby authorized and directed to appoint, in accordance with civil service and other provisions of law, such officers and other expert and clerical assistants as it may deem necessary, including a Beach Erosion Control Engineer. The Beach Erosion Control Engineer shall be a civil engineer registered under the Civil Engineers' Act and shall have had not less than ten (10) years' experience in beach and shore line protection, improvement, and development. It shall be his duty:

(a) To study and report upon problems of beach erosion and means for the development, protection and improvement of beaches and shore line areas.

(b) To investigate and report to the State Park Commission upon beach areas suitable or needed for public recreation purposes and to prepare plans for the improvement, development, and protection of public beaches.

(c) To cooperate with all agencies of government, Federal and State, for the purpose of carrying out the provisions of this code, and to act in an advisory capacity on beach erosion, protection, improvement and development when requested by political subdivisions of the State, when so authorized by the State Park Commission.

(d) To assist in the preparation of a State master plan of shore line development, which plan shall take into consideration, correlate and coordinate, as nearly as feasible, the master plans of shore line development of the various coastal counties of the State. (Amended by Stats. 1947, ch. 797, §1.)

506.7. The State Park Commission shall have power to adopt, alter, change or amend any State master plan of shore line development. (Added by Stats. 1943, ch. 1123, §2, p. 3067.)

507. The Division of Mines shall be administered through a chief who shall be known as the State Mineralogist. He shall be a technically trained mining engineer, appointed by the director upon nomination by the State Mining Board. General policies for the guidance of the Division of Mines shall be determined by a State Mining Board, which shall consist of five members appointed by and holding office at the pleasure of the Governor.

508. The Division of the Department of Natural Resources for the supervision of oil and gas shall be in charge of a chief, known as the State Oil and Gas Supervisor.

509. The salaries of the chiefs of the Divisions of Forestry and Parks shall be fixed by the director with the approval of the Governor. The director and the chief of each division, before entering upon his duties, shall execute and deliver to the State an official bond in the sum of twenty-five thousand dollars conditioned upon the faithful performance of his duties.

510. The members of the Board of Forestry and the State Park Commission shall serve without compensation, but shall be entitled to their actual necessary expenses incurred in the performance of their duties.

511. For the purpose of disseminating information relating to the activities, powers, duties, or functions of the Department of Natural Resources, the department, with the approval of the Department of Finance, may issue publications, construct and maintain exhibits, and perform such acts and carry on such functions as in the opinion of the Director of Natural Resources will best tend to disseminate such information.

Such publications may be distributed free of charge to public libraries and to other State departments and State officers. The department may exchange copies with contemporary publications.

All money received by the department from the sale of publications, exclusive of money received by any separate division of the department from the sale of publications, shall be paid into the State Treasury to the credit of the General Fund. (Added by Stats. 1939, ch. 95, §1, p. 1217; Amended by Stats. 1943, ch. 488, §1, p. 2031.)

512. The Department of Natural Resources may expend the money in any appropriation or in any special fund in the State Treasury made available by law for the administration of the statutes the administration of which is committed to the department, or for the use, support, or maintenance of any board, bureau, commission, department, office, or officer whose duties, powers, and functions have been transferred to and conferred upon the department. Such expenditures by the department shall be made in accordance with law in carrying out the purposes for which the appropriations were made or the special funds created.

513. The department shall have possession and control of all records, books, papers, offices, equipment, supplies, moneys, funds, appropriations, land and other property, real or personal held for the benefit or use of all bodies, offices, and officers whose duties, powers, and functions have been transferred to and conferred upon the department.

514. Nothing in this code is intended to supersede, modify or change the effect of the enactment of section 373g of the Political Code, and wherever in this code refer-

ence is made to any officer or agency of the Department of Natural Resources, it is made in the sense and with the same legal effect as was attributable thereto in the statute whence derived and which would continue to be so attributable but for the adoption of this code.

DIVISION 2. MINES AND MINING

Chapter 1. Definitions

2001. Unless the context otherwise requires, the definitions hereinafter set forth shall govern the construction of Division 2 of this code.

2002. "Department" in reference to the government of this State, means the Department of Natural Resources.

2003. "Division" in reference to the government of this State, means the Division of Mines in the Department of Natural Resources.

2004. "Person" includes any individual, firm, association, corporation, or any other group or combination acting as a unit.

Chapter 2. The Division of Mines

2200. For the purposes of this chapter "mine" includes all mineral bearing properties of whatever kind or character, whether underground, quarry, pit, well, spring or other source from which any mineral substance is or may be obtained. "Mineral" for the purposes of this chapter includes all mineral products both metallic and nonmetallic, solid, liquid or gaseous, and mineral waters of whatever kind or character.

2201. The State Mineralogist shall employ competent geologists, field assistants, qualified specialists, and office employees when necessary in the execution of the plans and operations of the division under this chapter and shall fix their compensation.

2202. The State Mineralogist shall maintain offices, and a museum, library, and laboratory in San Francisco for the purposes provided in this chapter.

2203. The State Mineralogist shall make a biennial report to the Governor on or before the fifteenth day of September next preceding the regular session of the Legislature.

2204. The State Mineralogist may receive on behalf of this State, for the use and benefit of the division, gifts, bequests, devices, and legacies of real or other property and may use the same in accordance with the wishes of the donors. If no instructions are given by the donors, the State Mineralogist shall manage, use, and dispose of the gifts, bequests, and legacies for the best interests of the division and in such manner as he may deem proper.

2205. The State Mineralogist shall:

(a) Make, facilitate, and encourage special studies of the mineral resources and mineral industries of the State.

(b) Collect statistics concerning the occurrence and production of the economically important minerals and the methods pursued in making their valuable constituents available for commercial use.

(c) Make a collection of typical geological and mineralogical specimens, especially those of economic and commercial importance, such collection constituting the museum of the division.

(d) Provide a library of books, reports, and drawings bearing upon the mineral industries, the sciences of mineralogy and geology, and the arts of mining and metallurgy, such library constituting the library of the division.

(e) Make a collection of models, drawings, and descriptions of the mechanical appliances used in mining and metallurgical processes.

(f) Preserve and so maintain such collections and library as to make them available for reference and examination, and open to public inspection at reasonable hours.

(g) Maintain, in effect, a bureau of information concerning the mineral industry of this State to consist of such collections and library, and arrange, classify, catalogue, and index the data therein contained, in a manner to make the information available to those desiring it.

(h) Issue from time to time such bulletins as he may deem advisable concerning the statistics and technology of the mineral industries of this State.

2206. The State Mineralogist may prepare a special collection of ores and minerals of California to be sent to or used at any world's fair or exposition in order to display the mineral wealth of the State.

2207. The owner, lessor, lessee, agent, manager, or other person in charge of any mine of whatever kind or character within the State shall forward to the State

Mineralogist, upon his request, at his office, not later than the thirty-first day of March in each year, a detailed report upon forms which will be furnished showing the character of the mine, the number of men employed, the method of working the mine and the general condition thereof, and the total mineral production for the past year. He shall also furnish any additional information relative to such mine that the State Mineralogist may from time to time require for the proper discharge of his official duties. Any such person who fails to comply with the provisions of this section is guilty of a misdemeanor.*

2208. The State Mineralogist or a qualified assistant may at any time enter or examine any and all mines, quarries, wells, mills, reduction works, refining works, and other mineral properties or working plants in this State in order to gather data to comply with the provisions of this chapter.

2209. The State Mineralogist may fix a price upon and dispose of to the public all publications of the division, including reports, bulletins, maps, registers, or other publications. The price shall approximate the cost of publication and distribution. He may also furnish the publications of the division to public libraries without cost and may exchange publications with geological surveys, scientific societies, and other like bodies.

2210. All money received by the division from sales of publications issued by the division shall be deposited at least once each month in the State treasury to the credit of the General Fund. (Amended by Stats. 1945, ch. 425, §1.)

* Sec. 19 of the Penal Code of California provides: "Except in cases where a different punishment is prescribed by this code, every offense declared to be a misdemeanor is punishable by imprisonment in a county jail not exceeding six months, or by a fine not exceeding five hundred dollars, or both."

U. S. ATOMIC ENERGY COMMISSION ANNOUNCES PROGRAM TO STIMULATE PRODUCTION OF DOMESTIC URANIUM*

The United States Atomic Energy Commission today announced a three-point program to stimulate the discovery and production of domestic uranium by private competitive enterprise.

The major elements of the program are:

1. Government guaranteed ten-year minimum prices for domestic refined uranium, high-grade uranium ores and mechanical concentrates.
2. A bonus of $10,000 for the discovery and production of high-grade uranium ores from new domestic deposits.
3. Government guaranteed three-year minimum prices for the low-grade carnotite- and roscoelite-type uranium-vanadium ores of the Colorado plateau area and Government operation of two vanadium-uranium plants in that area.

John K. Gustafson, Director of the AEC Division of Raw Materials, describes the program as ''an opportunity for prospectors and mining companies to participate in the nation's atomic energy industry by exercise of their own initiative and with the profit incentive. The Commission recognizes that, in line with the policies expressed in the Atomic Energy Act of 1946, development and production of uranium ores can be stimulated most effectively by the type of private operations responsible for the growth and efficiency of the American mining industry. The interest and energies of individual prospectors, small operators and large mining companies are now required in the production of source materials for atomic energy.''

The AEC plans to continue and expand its own exploration, development and research relative to raw materials. This work is designed to aid rather than limit the activities of private enterprise in prospecting, ore production and ore benefication. Commission-sponsored diamond drilling and geological surveys in the Colorado Plateau area, and in other sections of continental United States and its territories, will cover private as well as public lands. Information developed by the AEC concerning individual deposits will be made available to the owners of these deposits, but for security reasons may not be released for publication. In general, deposits of uranium discovered by the Commission on public lands are expected to be made available for development by private operators.

Uranium in deposits on the public lands, and other lands owned by the United States, is now reserved to the United States, subject to mineral rights established on or before August 1, 1946 (the date of the Atomic Energy Act). However, the Commission's guaranteed minimum prices have been made applicable to deliveries to it of ores containing such reserved uranium in consonance with the Commission's authority to pay fair and reasonable sums, including profits, for discovery, delivery, and other services performed with respect to such ores. The Commission wishes to encourage prospecting for new deposits of uranium ores on the public domain and has been advised by the Department of the Interior, which administers the disposition of the public lands, that valid locations may be staked on such deposits if the uranium occurs in a deposit which is valuable because of other minerals. In the unlikely event of the discovery of a deposit of uranium-bearing ore which does not contain some other

* United States Atomic Energy Commission, (Washington 25, D. C.) release for the press, No. 96, April 10, 1948.

valuable mineral, the Commission, upon notice, will take steps to protect the prospector's equity.

The price and bonus program, which is detailed in circulars available from the Commission, is essentially as follows:

DOMESTIC REFINED URANIUM, HIGH-GRADE URANIUM-BEARING ORES AND MECHANICAL CONCENTRATES

The AEC guarantees minimum prices for delivery to it of domestic refined uranium, high-grade uranium-bearing ores and mechanical concentrates in accordance with the terms of its circular for 10 calendar years. The guaranteed minimum prices are:

Uranium-bearing Ores and Concentrates. $3.50 per pound of recoverable uranium oxide, less the cost per pound to refine to necessary purity as determined by the AEC after assay of a representative sample.

Refined Uranium Products. $3.50 per pound of uranium oxide.

The prices established are minimum prices for small lots. Higher prices may be established by negotiation with the seller for larger quantities, taking into consideration such factors as refining and milling costs, transportation costs and other applicable items. The Commission also will give consideration to the presence of recoverable gold, silver, radium, thorium and other valuable constituents of the ores, depending upon the cost of recovery.

BONUS FOR DISCOVERY AND PRODUCTION OF DOMESTIC URANIUM ORES

As a special incentive to stimulate prospecting for new high-grade domestic uranium deposits, other than deposits of so-called carnotite or roscoelite ores, the AEC will pay in addition to the prices established under the purchase schedule a bonus of $10,000 for the production, upon delivery to the Commission, of the first 20 short tons of uranium ore or mechanically produced concentrates assaying 20 percent or more uranium oxide from any single lode or placer mining location on the public domain which has not previously been worked for uranium, or from a comparable area on private property. The discovery bonus will be paid only once for the production of ore from any single lode or placer location but the same person may receive a bonus for the production from each new location. Although this offer does not apply to production of carnotite or roscoelite ores, a special development allowance in addition to the base price has been provided to encourage discoveries of such ores.

URANIUM-BEARING CARNOTITE- OR ROSCOELITE-TYPE ORES OF THE COLORADO PLATEAU AREA

The AEC guarantees a minimum price schedule for delivery to it of carnotite- or roscoelite-type ores at Monticello, Utah, or Durango, Colorado. The minimum prices, effective for three calendar years, are the highest per ton of average ore ever paid in the Colorado plateau area. Independent producers are currently receiving $13.80 per ton from private industry for ore containing 2 percent vanadium oxide and 0.2 percent uranium oxide. Under the Atomic Energy Commission schedule the producers will receive $20.40 per ton for this grade ore. The prices established by the Commission are based upon a comprehensive study of mining costs, current and past prices paid for ores by vanadium com-

panies and by the Metals Reserve Company during the war, and numerous discussions with independent miners and representatives of the larger companies. The Commission has concluded that the increase in prevailing prices is necessary to stimulate exploration and increased production.

The schedule provides for payment of $1.50 per pound of uranium oxide (U_3O_8) for the delivery of ores assaying 0.20 percent, plus a development allowance of 50 cents per pound. Premiums will be paid for delivery of certain higher grade ores and a lower price will be paid for delivery of ores containing less than 0.20 percent uranium oxide with no payment for ores containing less than 0.10 percent. Payment also will be made based on the vanadium oxide content of the ore at 31 cents per pound for an amount not exceeding ten pounds for each pound of uranium oxide. No payment will be made for vanadium oxide in excess of this amount.

It is expected that the Monticello purchase depot will be ready to receive ore during July 1948 and that the Durango depot will be in operation shortly thereafter. Ore buying will be handled by private contractor. The Commission is being advised on the administration of this program at the present time by the American Smelting and Refining Company.

Circulars describing the ore-buying program are available from the Commission's Washington, D. C. headquarters, from the AEC office in Grand Junction, Colorado, and from the office of the AEC at 70 Columbus Avenue, New York, N. Y.

UNITED STATES ATOMIC ENERGY COMMISSION DOMESTIC URANIUM PROGRAM

Circular No. 1
Ten-Year Guaranteed Minimum Price

§60.1 *Ten-Year Guaranteed Minimum Price*—(a) *Guarantee.* To stimulate domestic production of uranium and in the interest of the common defense and security the United States Atomic Energy Commission hereby establishes the guaranteed minimum prices specified in paragraph (b) of this section, for the delivery to the Commission, in accordance with the terms of this section during the ten calendar years following its effective date, of domestic refined uranium, high-grade uranium-bearing ores and mechanical concentrates, in not less than the quantity and grade specified in paragraph (e) of this section. This guarantee does not apply to uranium-bearing ores of the Colorado Plateau area, commonly known as carnotite-type or roscoelite-type ores, prices for which are established by §60.3.

NOTE: The term "domestic" in this section, referring to uranium, uranium-bearing ores and mechanical concentrates, means such uranium, ores, and concentrates produced from deposits within the United States, its territories, possessions and the Canal Zone.

(b) *Guaranteed Minimum Prices.* The following minimum prices are established:

(1) For uranium-bearing ores and mechanical concentrates, $3.50 per pound of U_3O_8 (uranium oxide) determined by the Commission to be recoverable, less cost per pound of refining such ores or concentrates to standards of purity required for the Commission's operations, to be determined by the Commission after assay of a representative sample.

(2) For refined uranium products, \$3.50 per pound contained U_3O_8 (uranium oxide).

Prices are f. o. b. railroad cars or trucks at shipping point designated by the Commission convenient to mine, mill, or refinery. Weights are avoirdupois dry weight.

(c) *Making an Offer.* Anyone who has domestic refined uranium, high-grade uranium-bearing ores, or mechanical concentrates of the quantity and grade specified in paragraph (e) of this section, may offer it for delivery to the Commission by sending a letter or telegram addressed as follows:

United States Atomic Energy Commission,
Post Office Box 30, Ansonia Station,
New York 23, N. Y.
Attention: Division of Raw Materials.

With each offer there should be furnished a representative ten-pound sample and the following information:

(1) Location of property;

(2) Character of material offered for delivery (state whether refined uranium, mechanical concentrates, or uranium-bearing ores, indicating approximate composition);

(3) Amount of material offered;

(4) Location of material offered;

(5) Origin of material if offered by other than producer;

(6) If material is owned, in whole or in part, by any person other than the person making the offer, the name of each person having such ownership and nature of his rights; and

(7) Name and address of person making the offer.

NOTE: The reporting requirements hereof have been approved by the Bureau of the Budget pursuant to the Federal Reports Act of 1942.

(d) *Purchase Contract.* Upon receipt of an offer and sample, an analysis of the sample will be made. If the sample and the information furnished are determined by the Commission to meet the conditions of this section, the Commission will forward to the person making the offer a form of contract containing applicable terms and conditions ready for his acceptance. Prices will be not less than the applicable prices of paragraph (b) of this section.

(e) *Minimum Quantity and Grade.* No delivery will be accepted under this section of less than ten short tons (2,000 pounds per ton) of ores or mechanical concentrates, nor of ore or mechanical concentrates which assay less than 10 percent U_3O_8 by weight. No delivery will be accepted under this section of less than one short ton of refined uranium, nor of refined uranium which contains by weight less than 97 percent U_3O_8 in black uranium oxide or 87 percent U_3O_8 in sodium uranate. However, the Commission will be interested in negotiating reasonable terms with respect to deliveries of high-grade ores and refined products in lesser quantities and grades than those specified in this section.

(f) *Large Quantities or Special Conditions.* The prices established in paragraph (b) of this section are minimum prices. The Commission may by negotiations establish higher prices for guaranteed delivery of lots of ores or mechanical concentrates substantially in excess of ten short tons, or for lots of refined uranium substantially in excess of one short ton. The Commission also may by negotiation establish higher prices for

delivery of ores, mechanical concentrates, or refined uranium under other special conditions, taking into consideration such factors as refining and milling costs, transportation costs, and other applicable factors.

(g) *Other Valuable Minerals.* In making payment for material delivered to it in accordance with this section, the Commission will give consideration to the existence of recoverable gold, silver, radium, thorium, or any other valuable constituent in the light of the cost of recovery.

(h) *Licenses.* Arrangements will be made by the Commission for the issuance of licenses, pursuant to the Atomic Energy Act of 1946, covering deliveries of source material to the Commission under this section. (Sec. 5 (b), 60 Stat. 761)

Effective Date. This circular will become effective at midnight, April 11, 1948.

Dated at Washington, D. C., this 9th day of April 1948.

By order of the Commission.

WALTER J. WILLIAMS,
Acting General Manager.

Circular No. 2

Bonus for the Discovery and Production of High-Grade Domestic Uranium Ore

§60.2 *Bonus for the Discovery and Production of High-grade Domestic Uranium Ore*—(a) *Discovery and Production Bonus.* To stimulate prospecting for, discovery of, and production from new high-grade domestic uranium deposits and in the interest of the common defense and security the United States Atomic Energy Commission will pay, in addition to the guaranteed minimum price established in §60.1, a bonus of $10,000 for delivery to the Commission, after the effective date of this section, of the first 20 short tons (2,000 pounds avoirdupois dry weight per ton) of uranium-bearing ores or mechanical concentrates assaying 20 percent or more U_3O_8 by weight from any single mining location, lode or placer, which has not previously been worked for uranium (or in the case of production from lands not covered by such a mining location, from an area comparable thereto, as determined by the Commission). This bonus offer does not apply to delivery of ores of the Colorado Plateau area commonly known as carnotite-type or roscoelite-type ores; under §60.3, the Commission has established guaranteed minimum prices for delivery of such ores including a development allowance and premiums for better grade.

NOTE: The term "domestic" in this section, referring to uranium, uranium-bearing ores and mechanical concentrates, means such uranium, ores and concentrates produced from deposits within the United States, its territories, possessions and the Canal Zone.

(b) *Nature of Bonus.* The bonus of $10,000 offered in this section is a bonus to encourage the discovery of new uranium resources. However, it will be paid, not for discovery alone, but only in connection with delivery to the Commission, pursuant to §60.1, of ores produced from the location, as an independent and additional part of the price established by the Commission under that section.

(c) *Who May Claim.* The person lawfully entitled to deliver ore to the Commission pursuant to §60.1, may claim the bonus offered in paragraph (a) of this section. A bonus will be paid only once for production of ores from any single lode or placer location (or, in the case of produc-

tion from lands not covered by such a location, from an area comparable thereto, as determined by the Commission). The Commission expressly reserves the right to determine whether production from a given location is the first production from such location for the purposes of this section or whether such location or property has previously been worked for uranium, whether production is such as to which a bonus has already been paid, or whether for any other reason a bonus is not payable. In making this determination the Commission will be guided by the mining laws of the United States which provide, generally, that lode locations may extend in lode or vein formation up to 1,500 feet along the vein and in width 300 feet on each side of the middle of the vein, the end lines of the location being parallel to each other; and that placer locations may not be greater than 20 acres for each location or 160 acres in a single location for up to eight locators. The fact that a bonus has already been received will not prevent the payment of another bonus to the same person with respect to production from a different location.

(d) *Notice of Discovery and Production.* Notice of the discovery of a uranium deposit and of production therefrom believed to meet the requirements of paragraph (a) of this section should be forwarded to the Commission by letter or telegram, to the address specified in paragraph (f) of this section, together with an offer to deliver such ore to the Commission under §60.1. In addition to the information and the 10-pound sample required under §60.1, the following must be furnished:

(1) A brief description of the location or property indicating its size and relationship to mineral monuments or the public land surveys;

(2) Name of owner of record of property;

(3) Location of Recorder's Office where ownership is recorded.

NOTE: The reporting requirements hereof have been approved by the Bureau of the Budget pursuant to the Federal Reports Act of 1942.

(e) *Inspection of Claim.* Upon receipt of a notice of discovery and sample, forwarded as required in §60.1, an analysis of the sample will be made. If the sample and supporting data indicate the claim is likely to meet the requirements of paragraph (a) of this section, an inspection of the property and verification of the weights and assays of material produced will be undertaken by the Commission. On the basis of a report of such inspection and verification, if favorable, the Commission will determine the quantity of ore produced. If this determination indicates that the production requirements established in paragraph (a) of this section have been met, the Commission will pay the bonus in addition to the price established under §60.1, when delivery of such ore is completed.

(f) *Inquiries and Communications.* Inquiries about this section and all other communications should be addressed as follows:

United States Atomic Energy Commission,
Post Office Box 30, Ansonia Station,
New York 23, N. Y.
Attention: Division of Raw Materials.

(g) *Licenses.* Arrangements will be made by the Commission for the issuance of licenses, pursuant to the Atomic Energy Act of 1946, covering deliveries of source material to the Commission under this section. (Sec. 5 (b), 60 Stat. 761)

Effective Date. This circular will become effective at midnight, April 11, 1948.

Dated at Washington, D. C., this 9th day of April 1948.

By order of the Commission.

WALTER J. WILLIAMS,
Acting General Manager.

Circular No. 3

Guaranteed Three-Year Minimum Price for Uranium-Bearing Carnotite-Type or Roscoelite-Type Ores of the Colorado Plateau Area

§60.3 *Guaranteed Three-Year Minimum Price for Uranium-Bearing Carnotite-Type or Roscoelite-Type Ores of the Colorado Plateau Area*—(a) *Guarantee.* To stimulate domestic production of uranium-bearing ores of the Colorado Plateau area, commonly known as carnotite-type or roscoelite-type ores, and in the interest of the common defense and security the United States Atomic Energy Commission hereby establishes the guaranteed minimum prices specified in Schedule I of this section, for the delivery of such ores to the Commission, at Monticello, Utah, and Durango, Colorado, in accordance with the terms of this section during the three calendar years following its effective date.

NOTE: In §§60.1 and 60.2 (Domestic Uranium Program, Circulars No. 1 and 2), the Commission has established guaranteed prices for other domestic uranium-bearing ores, mechanical concentrates, and refined uranium products.

(b) *Definitions.* As used herein, the term "buyer" refers to the U. S. Atomic Energy Commission, or its authorized purchasing agent. The term "seller" refers to any person offering uranium ores for delivery to the Commission. Weights are avoirdupois dry weight.

(c) *Deliveries of not to Exeed 1,000 Tons per Year.* To aid small producers, any one seller may deliver without a written contract but otherwise in accordance with this section up to, but not exceeding, 1,000 short tons (2,000 pounds per ton) of ores during any calendar year.

(d) *Deliveries in Excess of 1,000 Tons per Year.* Sellers desiring to deliver in excess of 1,000 short tons (2,000 pounds per ton) of ores during any calendar year will be required to execute a contract with the Commission. Buyer is not obligated to purchase in excess of 5,000 short tons of ores from any one seller during any calendar year, although buyer may elect to do so.

(e) *Delivery.* Seller, at his own expense, shall deliver and unload all ores at the buyer's depots at Monticello, Utah, or Durango, Colorado. (Additional depots may be established at later dates.) Deliveries shall be in lots of not less than 10 short tons (2,000 pounds per ton), but such lots may be delivered in more than one load. Days and hours during which ore may be delivered to a depot will be posted at the depot. The exact date on which ore buying will commence at the two depots mentioned will be announced later; no deliveries will be accepted prior to this announced date. It is expected that the Monticello depot will be ready to receive ore during the month of July 1948, and that the Durango depot will be in operation shortly thereafter.

(f) *Weighing, Sampling and Assaying.* Buyer will bear the cost of weighing, sampling and assaying. The net weight of each load will be determined by the buyer's weighmaster on scales which will be provided

by the buyer at or in the vicinity of the purchase depot and such weight will be accepted as final. A weight ticket will be furnished seller or his representative for each load. Each lot of ores will be sampled promptly by the buyer according to standard practice and such sampling will be accepted as final. Seller or his representative may be present at the sampling at his own expense. The absence of seller or his representative shall be deemed a waiver of this right. Buyer will make moisture determination according to standard practices in ore sampling. All final samples will be divided into four pulps and distributed as follows: (1) the seller, or his representative, will receive one pulp; (2) the buyer will retain one pulp; (3) the other two pulps will be reserved for possible umpire analysis. The buyer's pulp will be assayed by the buyer. The seller may, if he desires, and at his own expense, have his pulp assayed by an independent assayer. In case of disagreement on assays as to any constituent of the ores, an umpire shall be selected in rotation from a list of umpires approved by the buyer whose assays shall be final if within the limits of the assays of the two parties; if not, the assay which is nearer to that of the umpire shall prevail. The party whose assay is the farther from that of the umpire will pay the cost of the umpire's assay for the constituent of the ores which is in dispute. In the event that the umpire's assay is equally distant from the assay of each party, costs will be split equally. In case of seller's failure to make or submit assays, buyer's assays shall govern. After sampling, the ores may be placed in process, commingled, or otherwise disposed of by buyer.

(g) *Payment.* Buyer will make payment promptly on payment dates to be posted at depots. Payment will not be made until an entire minimum lot of ten short tons (2,000 pounds per ton) has been delivered and accepted, unless special arrangements have been agreed upon by buyer, in which case there may be an extra charge for assaying and sampling. The analysis of any one lot consisting of more than one load will be based on a composite of the samples taken. Moisture determinations, analyses and settlement sheets, together with the check in payment, will be mailed to seller.

(h) *Inquiries.* All inquiries concerning the provisions of this section, offers to deliver ores, or questions about the Commission's uranium program in the Colorado Plateau area should be addressed to:

United States Atomic Energy Commission,
Post Office Box 270,
Grand Junction, Colorado.
Telephone: Grand Junction 3000.

(i) *Licenses.* Arrangements will be made by the Commission for the issuance of licenses, pursuant to the Atomic Energy Act of 1946, covering deliveries of source material to the Commission under this section.

SCHEDULE I—MINIMUM PRICES, SPECIFICATIONS, AND CONDITIONS

1. *Quality and Size.* Ores will not be accepted by buyer under this section which, in buyer's judgment at time of acceptance:

(a) Contain less than 0.10% U_3O_8;

(b) Contain more than three parts of lime ($CaCO_3$) to one part of V_2O_5, or a total of more than 6% lime in the ore;

(c) Contain other impurities deleterious to buyer's extraction process;

(d) Contain lumps in excess of 12 inches in size.

2. *Prices.* Payment for delivery of the ores will be computed on the following basis:

(a) *Vanadium.* V_2O_5 at $0.31 per pound up to, but not exceeding, ten pounds of V_2O_5 for each pound of U_3O_8 contained in ores. No factor will be included for V_2O_5 in excess of ten pounds for each pound of U_3O_8. (Example: For an ore containing two pounds of U_3O_8 and twenty-five pounds of V_2O_5, payment would be made for twenty pounds of V_2O_5 at $0.31 per pound, but no payment would be made for the additional five pounds.) Such excess V_2O_5 shall be deemed to be buyer's property.

(b) *Uranium.* (1) Ores assaying less than 0.10% U_3O_8: no payment. Any such ores which are delivered to the purchase depot shall become the property of the buyer as liquidated damages for buyer's expense of weighing, sampling and assaying, and after sampling may be placed in process, commingled, or otherwise disposed of by buyer. If seller has any question as to the quality of his ore, it is suggested that before shipment and delivery to the purchase depot a representative sample be submitted to the buyer or to one of the umpires for assay at seller's expense. The buyer at his discretion may assay a limited number of samples without charge.

(2) Ores assaying 0.10% U_3O_8 up to 0.15%: price of $0.30 per pound of contained U_3O_8 for 0.10% ore, plus $0.30 per pound for each 0.01% above 0.10% U_3O_8 up to (but not including) 0.15%. (Example: The contained U_3O_8 in an ore assaying 0.13% U_3O_8 per ton would be paid for at $0.30 + (3 \times 0.30) = \$1.20$ per pound.)

(3) Ores assaying 0.15% U_3O_8 and more: base price of $1.50 per pound U_3O_8 content, plus a "development allowance" (at seller's option) of $0.50 per pound, or a total of $2.00 per pound U_3O_8 content.

(4) Premiums: $0.25 per pound for each pound of U_3O_8 in excess of 4 pounds U_3O_8 per short ton (2,000 pounds per ton) and an additional premium of $0.25 per pound for each pound in excess of ten pounds U_3O_8 per ton of ore.

(Example: U_3O_8 payments for a short ton of ores assaying 0.6% U_3O_8 would be as follows:

Base price 12 lbs. @ $1.50	$18.00
Development allowance 12 lbs. @ $0.50	6.00
Premium 8 lbs. (12–4) @ $0.25	2.00
Additional premium 2 lbs. (12–10) @ $0.25	.50
Total U_3O_8 payments	26.50)

(c) Assays shall be adjusted to the nearest 0.01% for purposes of payment.

NOTES: 1. The "development allowance" of $0.50 per pound of U_3O_8 contained in ores assaying 0.15% U_3O_8 or more, is offered by buyer in recognition of the expenditures necessary for maintaining and increasing the developed reserves of uranium ores. Sellers accepting this allowance are deemed to agree to spend such funds for the development or exploration of their properties. Sellers delivering less than 1,000 short tons per calendar year will not be required to submit an accounting record of expenditures for development or exploration pursuant to this agreement but sellers delivering in excess of 1,000 short tons per calendar year will be required, under the terms of their contracts, to submit proof satisfactory to the Commission that funds equivalent to the amount received as development allowance have been spent for development or exploration during the contract period or within six months thereafter.

2. Commitments by the Commission to accept delivery of ores are limited to the provisions of this section, as amended from time to time, or to written contracts between the Commission and sellers. Other commitments purporting to be made by the Commission's field personnel or other agents of the Commission will not bind the Commission unless they are in accord with the provisions of this circular or other official circulars.

3. Weights are avoirdupois dry weight; tons are short tons (2,000 pounds per ton).

(Sec. 5 (b), 60 Stat. 761)

Effective Date. This circular will become effective at midnight, April 11, 1948.

Dated at Washington, D. C., this 9th day of April 1948.

By order of the Commission.

WALTER J. WILLIAMS,
Acting General Manager.

PUBLICATIONS OF THE CALIFORNIA STATE DIVISION OF MINES*

OUTLINE OF REPORT

INTRODUCTION

The principal publications of the California State Division of Mines are at present the quarterly *California Journal of Mines and Geology,* issued in January, April, July, and October of each year; and a series of *Bulletins.* A monthly news release, *Mineral Information Service,* designed to inform the public of discoveries, operations, markets, statistics, and new publications concerning the mineral resources and industry of California, is distributed to the public free upon request. The latter, however, is not part of the regular publication series.

This paper contains a complete list of publications issued by the California State Division of Mines[1] to July 1, 1948. These publications include maps (M), special publications (SP), preliminary reports (PR), registers of mines (RM), reports of the State Mineralogist (R), California Journal of Mines and Geology (J) (which supersedes the reports of the State Mineralogist), and bulletins (B).

For the convenience of persons who wish to consult publications of the Division of Mines, a list of library holdings is included in this report.[2] Libraries may obtain, on temporary loan, most Division publications which are not among their holdings by writing to the Librarian, California State Division of Mines, Ferry Building, San Francisco 11, California.

In ordering publications, please give both series designation, as Bulletin 133, and the title. Give full address, plainly written. Prepayment is required, preferably in the form of money order or cashier's check; make remittance payable to State Division of Mines. Address remittances to California State Division of Mines, Ferry Building, San Francisco 11, California. There is no charge for postage.

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* Prepared by Elisabeth L. Egenhoff, Beth Collins, and Mary-Louise Burgess. This list includes all publications issued prior to September 1, 1948, and supersedes all previous lists of publications.

[1] Designated California State Mining Bureau, 1880-1927; California State Division of Mines and Mining, 1927-29.

[2] Libraries not included in the listing are invited to submit a record of their holdings of Division of Mines publications for inclusion in future editions of this report.

California residents should add 2½ percent sales[3] tax to list price of all publications except monthly or quarterly issues of *Reports of the State Mineralogist* and *Journals,* and subscriptions to the *Journal.*

PLEASE NOTE: ALL PUBLICATIONS MARKED WITH AN ASTERISK (*) ARE OUT OF PRINT; PRICES FOR THOSE THAT ARE STILL AVAILABLE ARE GIVEN IN THE LIST.

[3] California sales tax schedule:

Trans.	Tax	Trans.	Tax	Trans.	Tax
.01- .14	--	3.80- 4.19	.10	7.80- 8.19	.20
.15- .59	.01	4.20- 4.59	.11	8.20- 8.59	.21
.60- .99	.02	4.60- 4.99	.12	8.60- 8.99	.22
1.00- 1.39	.03	5.00- 5.39	.13	9.00- 9.39	.23
1.40- 1.79	.04	5.40- 5.79	.14	9.40- 9.79	.24
1.80- 2.19	.05	5.80- 6.19	.15	9.80-10.19	.25
2.20- 2.59	.06	6.20- 6.59	.16	10.20-10.59	.26
2.60- 2.99	.07	6.60- 6.99	.17	10.60-10.99	.27
3.00- 3.39	.08	7.00- 7.39	.18	11.00-11.39	.28
3.40- 3.79	.09	7.40- 7.79	.19	11.40-11.79	.29

MAPS (M)

*1. Preliminary mineralogical and geological map of the State of California, showing also private land grants, scale 1″ = 21 mi., 1891.

*2. Map of forest reserves in California, scale 1″ = 20 mi., 1907.

*3. Relief and mineral maps of California showing the topography and the approximate locations of all the principal mineral deposits together with the statistics of mineral production, scale 1″ = 30 mi., 1908.

*4. Map of Minaret district, Madera County, California, scale 1″ = 12 mi., 1908.

*5. Map of Madera County, California, showing boundaries of the National Forests, scale 1″ = 3 mi., 1909.

6. Map of Placer County, California, showing boundaries of the National Forests, scale 1″ = 3 mi. (approx.), 1909. Free.

*7. Map of Shasta County, California, showing boundaries of the National Forests, scale 1″ = 3 mi., 1909.

*8. Map of Sierra County, California, showing boundaries of the National Forests, scale 1″ = 1½ mi., 1909.

*9. Map of Siskiyou County, California, showing boundaries of the National Forests, scale 1″ = 4 mi., 1909.

*10. Map of Trinity County, California, showing boundaries of the National Forests, scale 1″ = 2 mi., 1909.

*11. Map of Tuolumne County, California, showing boundaries of the National Forests, scale 1¼″ = 3 mi., 1909.

*12. Map of El Dorado County, California, showing boundaries of the National Forests, scale 1″ = 2 mi., 1909.

*13. Map of California showing the approximate location of the principal mineral deposits, scale 1″ = 12 mi., 1911.

*14. Geological map of Inyo County, California, by C. A. Waring, scale 1″ = 4 mi., 1917.

*15. Map of southern portion of California showing the saline deposits and the desert sections of the state, scale 1″ = 12 mi. (approx.), 1905.

*16. Map of northern California, showing rivers and creeks which produced placer gold in 1932, scale 1″ = 20 mi. (approx.), by J. F. Bongard. Reprinted in Bulletin 135, as pl. 4.

17. Geologic map of California, scale 1″ = 8 mi., prepared under the direction of Olaf P. Jenkins, 1938. In six sheets, 32″ x 42″; sheets not sold separately. Lithographed in colors. Price, unmounted, $4.00. Price for mounted map furnished on request.

18. Outline geologic map of California showing locations of quicksilver properties (Economic mineral map of California No. 1—quicksilver), scale 1:1,000,000, prepared under the direction of Olaf P. Jenkins, 1939. Price 50¢.

19. Outline geologic map of California showing locations of chromite properties (Economic mineral map of California No. 3—chromite), scale 1:1,000,000, prepared under the direction of Olaf P. Jenkins, 1942. Price 60¢.

SPECIAL PUBLICATIONS (SP)

*1. First annual catalogue of the State Museum of California, being the collections made by the State Mining Bureau during the year ending April 16, 1881. 1888. 220 pp. (Revised edition; only one available).

*2. Contributions to the geology and mineralogy of California, by Wm. P. Blake. 1881. 15 pp.

*3. Catalogue of books, maps, lithographs, photographs, etc., in the library of the State Mining Bureau at San Francisco, May 15, 1884. 19 pp.

*4. Catalogue of the State Museum of California, vol. 2, being the collections made by the State Mining Bureau, from April 16, 1881 to May 15, 1884. 1884. 220 pp.

*5. Catalogue of the State Museum of California, vol. 3, being the collections made by the State Mining Bureau, from May 15, 1884 to March 31, 1887. 1887. 195 pp.

*6. Catalogue of the State Museum of California, vol. 4, being the collections made by the State Mining Bureau, from March 31, 1887 to August 20, 1890. 1890. 261 pp.

*7. Catalogue of the library of the California State Mining Bureau, San Francisco, Cal. September 1, 1892. 149 pp.

*8. Catalogue of west North American and many foreign shells with their geographical ranges, by J. G. Cooper. April 1894. 153 pp., Supplement 18 pp.

*9. Catalogue of the State Museum of California, vol. 5, being the collections made by the State Mining Bureau, from September 1, 1890 to March 30, 1897. 1899. 292 pp.

*10. Report of Board of Trustees for four years ending September, 1900. A. S. Cooper, State Mineralogist. 1901. 15 pp.

11. Reconnaissance of the Colorado Desert mining district, by Stephen Bowers, 1901. 19 pp., 2 illus. Free.

*12. Minerals of California and county atlas. 1902. 56 pp., 25 illus.

*13. Report of the Board of Trustees covering the fifty-second fiscal year ending June 30, 1901, and fifty-third fiscal year ending June 30, 1902. 1902. 17 pp.

Includes: General Appropriation Act providing for the support of the State Government for the fifty-second and fifty-third fiscal years, p. 2; Report of Board of Trustees of State Mining Bureau, pp. 3-12; Report of the State Mineralogist, by Lewis E. Aubury, pp. 13-17.

*14. Report of the Board of Trustees covering the fifty-fourth fiscal year ending June 30, 1903, and fifty-fifth fiscal year ending June 30, 1904. 1904. 14 pp.

Includes: General Appropriation Act providing for the support of the State Government for the fifty-fourth and fifty-fifth fiscal years, p. 2; Report of Board of Trustees of State Mining Bureau, pp. 3-8; Report of the State Mineralogist, by Lewis E. Aubury, pp. 9-14.

*15. Report of the Board of Trustees and State Mineralogist covering the fifty-sixth fiscal year ending June 30, 1905, and fifty-seventh fiscal year ending June 30, 1906. 1906. 20 pp.

Includes: Report of the Board of Trustees of the State Mining Bureau, pp. 3-7; Report of the State Mineralogist, by Lewis E. Aubury, pp. 8-19.

*16. Report of the Board of Trustees and State Mineralogist covering the fifty-eighth fiscal year ending June 30, 1907, and fifty-ninth fiscal year ending June 30, 1908. 1908. 27 pp.

Includes: Report of the Board of Trustees of the State Mining Bureau, pp. 3-10; Biennial report of the State Mineralogist, by Lewis E. Aubury, pp. 11-26.

*17. Report of the Board of Trustees and State Mineralogist covering the sixtieth fiscal year ending June 30, 1909, and sixty-first fiscal year ending June 30, 1910. 1910. 27 pp.

Includes: Report of the Board of Trustees of the State Mining Bureau, pp. 3-10; Biennial report of the State Mineralogist, by Lewis E. Aubury, pp. 11-27.

PRELIMINARY REPORTS (PR)

*1. Notes on damage by water in California oil fields. 1914. 4 pp.
Contains: Introduction, by F. McN Hamilton, p. 1; Coalinga field, by R. P. McLaughlin, pp. 1-4.

*2. Notes on damage by water in California oil fields. 1914. 4 pp.
Contains: Introduction, by F. McN Hamilton, p. 1; Midway and Sunset fields, by R. P. McLaughlin, pp. 2-4.

3. Manganese and chromium, by E. S. Boalich. *1st ed., 1917. 32 pp., 1 illus. . . . 1918. 2d ed., 46 pp., 2 illus., free.

*4. Tungsten, molybdenum and vanadium, by E. S. Boalich and W. O. Castello. 1918. 44 pp.

*5. Antimony, graphite, nickel, potash, strontium, tin, by E. S. Boalich and W. O. Castello. 1918. 44 pp.

*6. A review of mining in California during 1919, by Fletcher Hamilton. 1920. 43 pp., 1 illus.

*7. The clay industry in California, by E. S. Boalich, W. O. Castello, Emile Huguenin, C. A. Logan, W. Burling Tucker. 1920. 102 pp., 25 illus.

*8. A review of mining in California during 1921, by Fletcher Hamilton. 1922. 68 pp., 1 illus.

REGISTER OF MINES (RM)

*1. Register of mines and minerals, County of Calaveras, California, by M. B. Kerr. 1900. 27 pp., 1 map.

The following was included with report, also distributed separately:
* Map of Calaveras County, scale 1″ = 2 mi., by H. W. H. Penniman.

*2. Register of mines and minerals, County of Plumas, California, by J. A. Edman. 1900. 21 pp., 1 map.

The following was included with report, also distributed separately:
* Map of Plumas County, scale 1″ = 2 mi.

*3. Register of mines and minerals, County of Siskiyou, California, by J. M. Davidson. 1900. 27 pp., 1 map.

Contains: Map of Siskiyou County, scale 1″ = 4 mi. (approx.).

*4. Register of mines and minerals, County of Trinity, California, by W. S. Lowden. 1900. 25 pp., 1 map.

The following was included with report, also distributed separately:
* Map of Trinity County, scale 1″ = 2 mi.

*5. Register of mines and minerals, County of Nevada, California, by Charles E. Uren. 1901. 12 pp., 1 map.

Contains: Map of Nevada County, scale 1″ = 2 mi.

*6. Register of mines and minerals, El Dorado County, California, by J. F. Armstrong. 1902. 17 pp., 2 maps.

Contains: Map of El Dorado County, scale 1″ = 2 mi.; Economic and geological map of El Dorado County, p. 1.

*7. Register of mines and minerals, Inyo County, California, by A. V. Davidson. 1902. 14 pp., 1 map.

Contains: Map of Inyo County, scale 1″ = 5 mi.

*8. Register of mines and minerals, Lake County, California, by George Madeira. 1902. 9 pp., 1 map.

Contains: Map of Lake County, scale 1″ = 2½ mi. (approx.).

*9. Register of mines and minerals, Placer County, California, by Ivan H. Parker. 1902. 13 pp., 1 map.

Contains: Map of Placer County, scale 1″ = 3 mi.

*10. Register of mines and minerals, Shasta County, California, by M. E. Dittmar. 1902. 15 pp., 1 map.

Contains: Map of Shasta County, scale 1″ = 3 mi.

*11. Register of mines and minerals, San Bernardino County, California, by G. E. Bailey. 1902. 20 pp., 3 maps.

Contains: Map of San Bernardino County, scale 1″ = 6 mi.; Map of the mountains of the Mojave Desert, San Bernardino County, p. 3; Map of desert fissure springs, San Bernardino County, by R. P. McLaughlin, p. 4.

12. Register of mines and minerals, Amador County, California, by John B. Tregloan. 1903. 13 pp., 2 maps. Free.

Contains: Map of Amador County, scale 1″ = 1½ mi.; Economic geological map of the western half of Amador County, compiled from the maps of the U. S. Geological Survey, p. 2.

13. Register of oil wells, Los Angeles City, Los Angeles County, California, by Charles A. Blackmar. 1903. 13 pp., 1 map. Free.

Contains: Map of Los Angeles City oil fields.

*14. Register of mines and minerals, San Diego County, California, by Irving A. Hubon. 1903. 11 pp., 1 map.

Contains: Map of San Diego County, scale 1″ = 5 mi.

*15. Register of mines and minerals, Sierra County, California, by George F. Taylor. 1903. 14 pp., 2 maps.

Contains: Map of Sierra County, scale 1″ = 1½ mi.; Economic geological map of the western half of Sierra County, compiled from the maps of the U. S. Geological Survey, p. 1.

*16. Register of mines and minerals, Tuolumne County, California, by R. P. McLaughlin. 1903. 16 pp., 2 maps.

The following were included with report, also distributed separately: * Map of Tuolumne County, scale 1″ = ½ mi. (approx.); * Economic geological map of southwestern portion of Tuolumne County, compiled from the maps of the U. S. Geological Survey, p. 4.

*17. Register of mines and minerals, Butte County, California, by W. E. Thorne. 1904. 12 pp., 2 maps.

Contains: Map of Butte County, scale 1″ = 2 mi.; Map showing dredging lands adjacent to Feather River, Butte County, by O. W. Jasper, op. p. 4.

*18. Register of mines and minerals, Kern County, California, by Marion Aubury. 1904. 22 pp., 5 maps.

Contains: Map of Kern County, scale 1″ = 4 mi.; Kern River oil field, Kern County, by Paul W. Prutzman, p. 1; McKittrick oil field, Kern County, by Paul W. Prutzman, p. 2; Midway oil field, Kern County, by Paul W. Prutzman, p. 3; Sunset oil field, Kern County, by Paul W. Prutzman, p. 4.

*19. Register of mines and minerals, Mariposa County, California, by E. M. Wilkinson. 1904. 16 pp., 2 maps.

Contains: Map of Mariposa County, scale 1″ = 2½ mi.; Economic geological map of northwestern portion of Mariposa County, compiled from maps of U. S. Geological Survey.

20. Register of mines and minerals, Santa Barbara County, California, by Lew B. Harris. 1906. 9 pp., 4 maps. Free.

Contains: Map of Santa Barbara County, scale 1″ = 2 mi.; Summerland oil field, Santa Barbara County, p. 1; Santa Maria oil field, Santa Barbara County, by Lew B. Harris and J. A. Edman, p. 2; Los Alamos oil field, Santa Barbara County, by Lew B. Harris and J. A. Edman, p. 3.

*21. Register of mines and minerals, Yuba County, California, by Lew B. Harris. 1906. 14 pp., 3 maps.

Contains: Map of Yuba County, scale 1″ = 1½ mi.; Map showing dredging lands in the vicinity of Marysville, Yuba County, by Jason R. Meek, frontispiece; Economic geological map of Yuba County compiled from the maps of the U. S. Geological Survey, p. 2.

REPORTS OF THE STATE MINERALOGIST (R)

*First Annual Report of the State Mineralogist, from June 1, 1880 to December 1, 1880; Henry G. Hanks, State Mineralogist. 43 pp.

Contains: Report, by Henry G. Hanks, p. 3; Report of progress—history, pp. 3-8; Minerals of the Pacific Coast, pp. 8-9; Donations to the museum and library, pp. 9-14; Report of the chemist, by Edward Booth, pp. 15-17; Statement of receipts and expenditures of the California State Mining Bureau, December 1, 1880, by Henry G. Hanks, p. 18; Account of the Mining Bureau fund, San Francisco—a memorandum, p. 18; Loan collections, pp. 19-22; Prospecting, pp. 22-25; Paper on the occurrence of electrum in California, pp. 25-26; Quicksilver, pp. 26-27; Iron, pp. 27-30; Salt, pp. 30-31; Tin, pp. 31-32; Chromic iron, p. 32; Building materials, pp. 32-36; Clay deposits of the state, pp. 36-38; Platinum, p. 38; Buhr millstone, p. 38; Low grade ores, pp. 38-39; Black sands from hydraulic and placer mines, pp. 39-41; Alkaline lakes, p. 41; Extensive metallurgical works required, pp. 41-42; Supply of coal, p. 42; Lithology, pp. 42-43; Ethnology, p. 43; State manufactures, p. 43.

*Second Report of the State Mineralogist of California, from December 1, 1880 to October 1, 1882; Henry G. Hanks, State Mineralogist. 1882. 288 pp., 1 map; Appendix, 226 pp.

Contains: Report, by Henry G. Hanks, pp. 5-15; Report of the secretary, pp. 16-27; Placer, hydraulic, and drift mining, pp. 28-192 (General remarks, pp. 28-43; Hydraulic mining, pp. 44-118; Drift mining, p. 119; Treatment, properties, history of gold, pp. 119-157; General geology, pp. 157-170; Gold production of California, pp. 171-192); Iron ores and iron industries of California, pp. 193-201; Lumber and fuel, pp. 202-216; On the occurrence of salt in California and its manufacture, pp. 217-226; Mud volcanoes and Colorado Desert, pp. 227-240, 1 map; Diamonds in California, pp. 241-254; Notes on mica, pp. 255-261; Notes on roscoelite, pp. 262-264; On the occurrence of vivianite in Los Angeles County, p. 265; Diatoms and diatomaceous earths, pp. 266-270; Contribution to the ethnology and geology of the Pacific slope, by Philip Harvey, pp. 271-279; Glossary of terms in common use among the miners of California, pp. 280-288. **Appendix, papers supplementary to the Report of the State Mineralogist:** Forest trees of California, by A. Kellogg, pp. 3-116; Notes on hydraulic mining, by F. W. Robinson, pp. 117-129; Hydraulic and drift mining, by Henry De Groot, pp. 130-190; On the milling of gold quartz, by Melville Attwood, pp. 191-203; Rare minerals recently found in the state, by William P. Blake, pp. 205-223; Flour gold, by Almarin B. Paul, pp. 224-226.

*Third Annual Report of the State Mineralogist for the year ending June 1, 1883; Henry G. Hanks, State Mineralogist. 1883. Part I, 26 pp. Part II, 111 pp., 1 map, 21 illus.

Contains: **Part I:** Report, by Henry G. Hanks, pp. 5-26: List of donors, pp. 6-7; Library, p. 7; Publications, pp. 7-8; Laboratory work, p. 8; Financial condition of the Mining Bureau, pp. 9-13; Consideration of the affairs of the State Mining Bureau, pp. 13-15; Pacific Coast Mining Exposition, pp. 15-16; Pacific Coast Mineral Exposition, pp. 16-17; The Honduras exhibit, pp. 17-18; Visitors, p. 18; Death of Joseph Wasson, p. 18; Anticipated removal, p. 19; Danger of fire, p. 19; State map, p. 19; Economic considerations, pp. 20-21; Microscope slides, pp. 21-22; Post offices to which circulars were sent asking for samples of soil, pp. 22-25; List of the most important economic minerals, pp. 25-26. **Part II:** Report on the borax deposits of California and Nevada, by Henry G. Hanks, pp. 1-102, 1 map, 21 illus.; Index, pp. 103-111.

*Fourth Annual Report of the State Mineralogist for the year ending May 15, 1884; Henry G. Hanks, State Mineralogist. 1884. 410 pp., 8 illus.

Contains: Report, by Henry G. Hanks, pp. 5-27; Introduction, p. 5; Museum, p. 5; Publications, pp. 5-6; Library, p. 6; Visitors, p. 6; Donations, pp. 6-11; Statement of receipts and disbursements, State Mining

Bureau, p. 11; Chemical work, pp. 11-14; Pacific Coast Mineral Exposition of August 1883, pp. 15-27. California—information, general and statistical in relation to the agricultural, commercial, manufacturing, and other resources, interests, and industries of the state, pp. 28-59: Resources of California, etc., pp. 31-37; Agriculture, pp. 37-42; Viticulture—grapes, wines, and raisins, pp. 43-45; Statistical summary, by Henry De Groot, pp. 45-50; Manufacturing, mechanical, and other leading industries, pp. 50-59. Catalogue and description of the minerals of California as far as known, with special reference to those having an economic value, pp. 61-397, 6 illus.: Introduction, pp. 63-66; California minerals, pp. 67-397, 6 illus. Index, pp. 399-410.

*Fifth Annual Report of the State Mineralogist, for the year ending May 15, 1885; Henry G. Hanks, State Mineralogist. 1885. 235 pp., 4 maps, 14 illus.

Contains: Report, by Henry G. Hanks, pp. 5-13; History of former World's Fairs or International Expositions, pp. 13-50, 7 illus. California, pp. 51-120: Geography, p. 51; Forests, p. 52; Scenery, p. 52; Climate, p. 53; Agricultural resources and products, pp. 53-54; History, pp. 54-58; California mineral exhibit in the government building, pp. 58-62; On hanksite, by William Earl Hidden, pp. 62-64, 2 illus.; Mineralogical notes—a large crystal of hanksite, by Edward S. Dana and Samuel L. Penfield (from American Journal of Science, Aug. 1885), pp. 65-66; (Catalogue of the special California minerals shown at the Exposition), pp. 66-73; Gold, pp. 73-78; A simple working test for determining the quality of gold mechanically combined with auriferous vein matter, by Melville Attwood, pp. 78-87, 3 illus.; Catalogue of California gold mines represented in the Exposition, pp. 87-91; Silver, pp. 92-94; Quicksilver, pp. 95-96; Copper, pp. 96-98; Iron, pp. 98-101; Lead and base bullion, p. 101; Chrome ores, pp. 101-102; Hydrocarbons and mineral fuels, pp. 102-105; Borax, pp. 105-106; Manganese, p. 106; Tin, p. 106; Cement, pp. 106-107; Antimony, p. 107; Rocks and building stones, pp. 107-119; Sundries exhibited but not classified, pp. 119-120; Sundry special exhibits, p. 120. Gold mines of Georgia and other mining localities in the South, pp. 120-127; Mineral exhibits made by other states and territories in the government building, pp. 128-227, 1 illus.; Errata, p. 228; Index, pp. 229-235.

*Sixth Annual Report of the State Mineralogist, for the year ending June 1, 1886; Henry G. Hanks and William Irelan Jr., State Mineralogists. 1887. Part I, 145 pp., 2 maps, 3 illus. Part II, 222 pp., 36 illus.

Issued also in separate parts, as indicated below.

* (a) **Part I, 145 pp., 2 maps, 3 illus., contains:** History of the State Mining Bureau, p. 5; Present condition of the State Mining Bureau, pp. 5-6; Donations, p. 6; Correspondence, pp. 6-7; Chemical work, p. 7; Library, p. 7; Visitors, p. 7; Publications, p. 7; Sacramento State collection of minerals, p. 7, State maps, pp. 7-8; Catalogue, p. 8; Origin of the name California, pp. 8-10; General condition of mining in California, pp. 10-11; Mining economics, pp. 11-12; Importance of gold and gold mining, pp. 12-14; Bimetalism, pp. 14-15; Difficulties attending manufacturing in California, pp. 15-16; Building stones and building materials in California, pp. 16-34; Table of altitudes, pp. 34-53; Water power, p. 54; Irrigation, pp. 54-55; Record of strata in artesian well, pp. 56-57; Mineral springs in California, pp. 58-76; Calistoga silver mines, pp. 76-77; Arrow mining district, San Bernardino County, pp. 77-78; Mount St. Helena, pp. 78-79, 2 illus.; San Diego County, pp. 80-90, 2 maps, 1 illus.; California minerals, pp. 91-141; Index, pp. 143-145.

* (b) **Part II, 222 pp., 36 illus., contains:** Report of the Trustees of the State Mining Bureau, pp. 5-12; Report, by Wm. Irelan Jr., pp. 14-15; Amador County, pp. 15-24; Butte County, pp. 24-27, 3 illus.; Calaveras County, pp. 27-42, 5 illus.; El Dorado County, pp. 42-43; Fresno County, pp. 43-44; Nevada County, pp. 44-52, 1 illus.; Sierra County, pp. 52-59; Tuolumne County, pp. 59-60; Tabular statement of mills, p. 61; Conclusion, p. 62; Bullion production of mines of California for 12 months ending January 1, 1886, p. 63; Number of incorporated companies, p. 64; U. S. Patents, p. 64; Hydraulic mines enjoined, p. 64; Wells, Fargo & Co.'s

statistics, pp. 64-67; San Francisco Mint, pp. 67-68; Tables from report of Director of Mint, pp. 68-71; Table showing production of quicksilver in California for the year 1885, compiled by J. B. Randol, p. 72; Table showing production of quicksilver in California in the year 1886, compiled by J. B. Randol, p. 73; Hydromagnesite from Livermore, California, by F. Gutzkow, p. 74; Mine drainage, by Charles G. Yale, pp. 74-88, 3 illus.; Weight of quartz mills, pp. 88-90; Specifications for twenty-stamp gold mill, pp. 90-92; Concentration of gold and silver ores on the Pacific Coast, by J. M. Adams, pp. 92-116, 23 illus.; Golden Gate sulphuret concentrator, pp. 117-119, 1 illus.; Chlorination, by Wm. Irelan Jr., pp. 119-122; Mineral products of the United States, 1885, pp. 123-127; Summary of the mineral products of the U. S., cal. yrs. 1882-1885, pp. 128-131; U. S. mining laws, pp. 132-175; To find the value of gold or silver of a specimen, by C. H Aaron, pp. 176-177; Tables taken from "Practical Hydraulics," by P. M. Randall, pp. 178-182; Chapter IV, Part II, Title III, Political code of the State of California, pp. 183-189; Routes of travel, modes of conveyance, distances, etc., from San Francisco, pp. 190-214; Index, pp. 215-222.

*Seventh Annual Report of the State Mineralogist, for the year ending October 1, 1887; William Irelan Jr., State Mineralogist. 1888. 315 pp., 12 illus.

Contains: Report of Trustees of State Mining Bureau, pp. 5-8; Report, by Wm. Irelan Jr., p. 10; Origin of petroleum, pp. 10-11; Petroleum fields of California, pp. 11-16; Petroleum deposits in Venezuela, p. 16; Petroleum deposits in the Argentine Republic, pp. 16-17; Petroleum, where found, p. 17; Petroleum in Russia, pp. 17-23; Petroleum as a fuel, pp. 23-33, 3 illus.; Refining, pp. 34-37, 1 illus.; Chemistry of petroleum, pp. 37-41, 1 illus.; Locating for drilling, etc., pp. 41-47; Petroleum produced in and exported from the United States, 1864-1886 (from the Statistical Abstract of the United States, 1886), p. 48; Locating and patenting petroleum claims, pp. 49-50; Asphaltum and its uses, pp. 50-51; Laying of asphaltum on public thoroughfares, p. 51; Results of analyses of California asphaltum, pp. 51-53; Locating and patenting asphaltum claims, pp. 54-55; Natural gas in the Eastern states, pp. 55-56; Value of gas as a fuel, p. 56; Coal-land law and regulations thereunder, pp. 57-61; Petroleum, asphaltum, and natural gas in California, by W. A. Goodyear, pp. 65-114, 3 illus.; Coal in California, by W. A. Goodyear, pp. 117-178, 1 illus.; Natural gas in California, by Adolph H. Weber, pp. 181-191; Petroleum and asphaltum in northern California, by Adolph H. Weber, pp. 195-202, 3 illus.; Building stones, by A. Wendell Jackson, pp. 205-213; Precious metals product, United States of America and Mexico, report of Wells, Fargo & Co., pp. 217-219; Catalogue of Californian fossils, by J. G. Cooper, pp. 223-308; Index, pp. 309-315.

*Eighth Annual Report of the State Mineralogist for the year ending October 1, 1888; William Irelan Jr., State Mineralogist. 1888. 948 pp., 10 pls., 1 map, 106 illus.

Contains: Report of Trustees of State Mining Bureau, pp. 7-10, 2 illus.; California, pp. 12-16, 1 illus.; The Mining Bureau, pp. 16-22. Mineral resources of state, pp. 22-691: Alameda County, pp. 25-36, 4 illus.; Alpine County, pp. 36-40; Amador County, pp. 41-115, 12 illus.; Butte County, pp. 116-121; Calaveras County, pp. 121-157, 3 illus.; Colusa County, pp. 157-159; Contra Costa County, pp. 159-163; Del Norte County, pp. 163-164; El Dorado County, pp. 164-202; Fresno County, pp. 202-216; Humboldt County, pp. 216-223; Inyo County, by W. A. Goodyear, pp. 224-309, 15 illus. (including Owens Valley earthquake, pp. 288-309); Kern County, by W. A. Goodyear, pp. 309-324, 2 illus.; Lake County, pp. 324-329; Lassen County, pp. 329-332; Los Angeles County, pp. 332-335; Los Angeles County, by W. A. Goodyear, pp. 335-342; Marin County, p. 342; Mariposa County, pp. 343-349; Mendocino County, p. 349; Merced County, pp. 350-351; Modoc County, p. 352; Mono County, by H. A. Whiting, pp. 352-401, pls. 2-3, 1 illus.; Monterey County, pp. 402-411; Napa County, pp. 411-417; Nevada County, pp. 417-459, 1 illus.; Placer County, pp. 459-476; Plumas County, pp. 476-483; San Benito County, pp. 483-490; San Bernardino County, pp. 490-504; San Bernardino County, by W. A. Good-

year, pp. 504-512; San Diego County, pp. 512-516; San Diego County, by W. A. Goodyear, pp. 516-528; San Francisco County, pp. 528-529; San Luis Obispo County, pp. 529-533; San Mateo County, pp. 533-536; Santa Barbara County, pp. 536-540; Santa Clara County, pp. 540-550, 3 illus.; Santa Cruz County, pp. 550-556; Sacramento County, pp. 556-557; San Joaquin County, pp. 557-562; Shasta County, pp. 562-572; Sierra County, pp. 573-581; Siskiyou County, pp. 581-631; Solano County, pp. 631-632; Sonoma County, pp. 632-635; Stanislaus County, pp. 635-636; Sutter County, pp. 636-637; Tehama County, p. 637; Trinity County, pp. 637-643; Tulare County, by W. A. Goodyear, pp. 643-652; Tuolumne County, pp. 652-672, 1 illus.; Ventura County, pp. 676-678; Ventura County, by Stephen Bowers, pp. 679-690; Yolo County, p. 690; Yuba County, p. 691. Tabular statement of mills, arranged by counties, pp. 692-695; The milling of gold ores in California, by John Hays Hammond, pp. 696-735, 40 illus.; Drift mining in California, by Russell L. Dunn, pp. 736-770; Lithology of wall rocks, by Melville Attwood, pp. 771-784, 1 map, 9 illus.; Water wheels, by F. F. Thomas, pp. 785-803, 10 illus.; Notes on western lead smelting, by W. S. Keyes, pp. 804-831, pls. 1-6, 8-9; The Russell process, pp. 832-835; Notes on the hydrometallurgy of gold, by C. H. Aaron, pp. 836-846; Notes on the hydrometallurgy of silver, by C. H. Aaron, pp. 847-864; Natural and artificial cement, pp. 865-884, 1 illus.; Building stones, by A. Wendell Jackson, pp. 885-894; United States patents in California, pp. 895-896; Water rights, p. 897; The Alien Act, amendment of, p. 898; Imports of minerals and mineral products, pp. 898-899; Index, pp. 901-948.

Ninth Annual Report of the State Mineralogist, for the year ending December 1, 1889; William Irelan Jr., State Mineralogist. 1890. 352 pp., 8 pls., 51 illus. Price, cloth-bound volume, $1.15.

Contains: Report of Trustees of State Mining Bureau, pp. 7-11; Report, by Wm. Irelan Jr., pp. 15-19; California's variety and distribution of mineral wealth, pp. 19-20; Mining barely begun in California, p. 20; Debasing the bullion, pp. 20-21; Number of men engaged in mining, pp. 21-23; The Mongolian element, p. 23; The California miner, pp. 23-24; More common minerals and metals, p. 24; Quartz mining, p. 24; Number of quartz mills, stamps, drops, duty, etc., pp. 24-25; Cost of mining and milling ore—value and percentage of sulphurets, etc., p. 25; Our argentiferous ores, pp. 25-26; Hydraulic mining, 26; Booming, 26-27; Drift operations, pp. 27-29; River-bed mining—how carried on in California, pp. 29-30; The Big Bend tunnel, pp. 30-31; The northern tier of counties, pp. 31-32; The future of silver and its effects on California, pp. 32-35; Our gold bluffs and beaches, pp. 35-36; The dry and the seam diggings, the cement, pocket, and tailings deposits, nugget mining, crevicing, etc., pp. 36-38; Recovering auriferous gravel from sea beaches and river beds by means of dredges, submarine armor, and other apparatus, pp. 38-39; What has been attempted in other countries, pp. 39-40; Letter to the State Mineralogist, by Harry I. Willey, pp. 40-45; Letter to the State Mineralogist, by Ross E. Browne, pp. 45-46; Santa Clara County, by A. H. Weber, pp. 48-56; San Nicolas Island, by Stephen Bowers, pp. 57-61; Refining and coining of the precious metals, by Sven Gumbinner, pp. 62-104; The auriferous gravels of California, by John Hays Hammond, pp. 105-138, pls. 1-8, 20 illus.; San Diego County, by W. A. Goodyear, pp. 139-154; Santa Cruz Island, by W. A. Goodyear, pp. 155-170, 1 illus.; Stray notes on the geology of the Channel Islands, by Lorenzo G. Yates, pp. 171-174, 2 illus.; The mollusca of the Channel Islands of California, by Lorenzo G. Yates, pp. 175-178, 2 illus.; Insular floras, by Lorenzo G. Yates, pp. 179-188; 1 illus.; Los Angeles County, by E. B. Preston, pp. 189-210, 6 illus.; Lassen County, by E. B. Preston, pp. 211-213; San Bernardino County, by James H. Crossman, pp. 214-239; Pottery, by Linna Irelan, pp. 240-261, 5 illus.; River mining, by R. L. Dunn, pp. 262-281, 9 illus.; Slate quarrying in California, pp. 282-283; The value of fossils as indications of important mineral products, by J. G. Cooper, pp. 284-286; Clays, by W. D. Johnston, pp. 287-308, 5 illus.; California cement, pp. 309-311; Meteorological, by George E. Barnes, pp. 312-322; Coal product of California, p. 323; The manufacture of glass in California, by Henry De Groot, pp. 324-329; Mineral products of the United States in 1888, pp. 330-339; Index, pp. 341-352.

* Tenth Annual Report of the State Mineralogist for the year ending December 1, 1890; William Irelan Jr., State Mineralogist. 1890. 983 pp., 14 maps, 153 illus.

Contains: Report of the Trustees of State Mining Bureau, pp. 7-10; Report, by William Irelan Jr., pp. 13-22; Geology of the Mother Lode region, by Harold W. Fairbanks, pp. 23-90, 1 map, 31 figs.; Alameda County, by W. A. Goodyear, pp. 91-95; Alpine County, by Henry De Groot, pp. 96-97; Amador County, by J. A. Brown, pp. 98-123; Butte County, by J. A. Miner, pp. 124-146; Calaveras County, by J. A. Brown, pp. 147-152; Colusa County, by W. A. Goodyear, pp. 153-164; Contra Costa County, by W. A. Goodyear, p. 165; Del Norte County, by Alexander McGregor, pp. 166-168; El Dorado County, by Henry De Groot, pp. 169-182; Fresno County, by L. P. Goldstone, pp. 183-204, 1 map, 7 illus.; Humboldt County, by Alexander McGregor, pp. 205-208; Inyo County, by Henry De Groot, pp. 209-218; Kern County, by Myron Angel, pp. 219-226; Lake County, by W. A. Goodyear, pp. 227-271; Lassen County, by E. B. Preston, pp. 272-276; Los Angeles County, by E. B. Preston, pp. 277-283, 1 illus.; The Pico Cañon oil field, by Edward North, pp. 283-298, pls. 1-12, 1 map; Marin County, by W. A. Goodyear, p. 299; Mariposa County, by E. B. Preston, pp. 300-310, 1 illus,; Mendocino County, by Alexander McGregor, pp. 311-314; Mendocino County, by W. A. Goodyear, pp. 314-322; Merced County, by W. L. Watts, pp. 323-331; Modoc County, by E. B. Preston, pp. 332-335; Mono County, by Henry De Groot, pp. 336-344; Monterey County, by Myron Angel, pp. 345-348; Napa County, by W. A. Goodyear, pp. 349-363; Nevada County, by J. B. Hobson, pp. 364-398, 2 maps, 1 illus.; Orange County, by Stephen Bowers, pp. 399-409; Placer County, by J. B. Hobson, pp. 410-434, 6 maps, 6 illus.; The ancient river beds of the Forest Hill divide, by Ross E. Browne, pp. 435-465, 1 map, 16 illus.; Plumas County, by E. B. Preston, pp. 466-495, 4 illus.; Sacramento County, by W. L. Watts, pp. 496-514; San Benito County, by Myron Angel, pp. 515-517; San Bernardino County, its mountains, plains, and valleys, by Henry De Groot, pp. 518-539; San Diego County, by E. B. Preston, pp. 540-544, 1 illus.; The San Francisco ocean placer—the auriferous beach sands, by Henry De Groot, pp. 545-547; San Joaquin County, by W. L. Watts, pp. 548-566; San Luis Obispo County, by Myron Angel, pp. 567-585, 2 illus.; San Mateo County, by W. L. Watts, pp. 586-594; Santa Barbara County, by Myron Angel, pp. 595-599; The Santa Maria River, by J. B. Hobson, pp. 600-601, pls. 1-4; The gas well at Summerland, by F. H. Wheelan, pp. 601-603; Santa Clara County, by W. L. Watts, pp. 604-619; Santa Cruz County, by W. L. Watts, pp. 620-626, 1 illus.; Shasta County, by Alexander McGregor, pp. 627-641; Sierra County, by L. P. Goldstone, pp. 642-654, 1 map, 1 illus.; Siskiyou County, by J. B. Hobson, pp. 655-658; Solano County, by W. L. Watts, pp. 659-669; 1 illus.; Solano County, by W. A. Goodyear, pp. 669-671; Sonoma County, by W. A. Goodyear, pp. 672-679; Stanislaus County, by W. L. Watts, pp. 680-690; Sutter County, by E. B. Preston, p. 691; Tehama County, by E. B. Preston, pp. 692-694, 1 illus.; Trinity County, by Wm. P. Miller, pp. 695-727, pls. 1-8, 1 map; Tulare County, by Myron Angel, pp. 728-733; Tuolumne County, by L. P. Goldstone, pp. 734-757, 3 illus.; Ventura County, by Stephen Bowers, pp. 758-772; Report on the asphaltum mine of the Ventura Asphalt Company, by E. W. Hilgard, pp. 763-772, 2 illus.; Yolo County, by W. L. Watts, pp. 773-793; Yolo County, by W. A. Goodyear, pp. 793-794; Altitudes of various points northwest of San Francisco, p. 794; Yuba County, by E. B. Preston, pp. 795-802; Lead smelting, by F. C. von Petersdorff, pp. 803-851, 44 illus.; Mining of gold ores in California, by John Hays Hammond, pp. 852-882; Location of mines, by R. P. Hammond Jr., pp. 883-896, 6 illus.; The introduction of producer-gas at the Marsac mill, Park City, Utah, by C. A. Stetefeldt, pp. 897-898; The Colorado Desert, by Charles Russell Orcutt, pp. 899-919; Quicksilver mines and reduction works, by J. B. Randol, pp. 920-929; Mineral lands within the railroad grant, Eagle Bird mine, Nevada County, pp. 930-937; Gold extraction by potassium cyanide, by Wm. D. Johnston, pp. 938-942; Rincon Hill well, pp. 943-945; Meteorites, by F. C. von Petersdorff, pp. 946-951; Index, pp. 953-983.

The following are included with report, and were also issued separately: * Geological map of the Mother Lode region, scale 1" = 1 mi.; * Map of the Forest Hill divide, Placer County, California, scale 1" = 2000 ft.; Geological map of the Iowa Hill mining district, Placer County, scale 2" = 3000 ft., accompanied by cross-section plates, and longitudinal-section plates, free; * Geological map of Trinity County, Cal., scale 1" = 6 mi. (approx.).

Eleventh Report of the State Mineralogist (first biennial) two years ending September 15, 1892; William Irelan Jr., State Mineralogist. 1893. 612 pp., 4 maps, 73 illus. Price $1.50.

Contains: Editor's report to the Board of Examiners, by Charles G. Yale, pp. 3-7; Report of Trustees of State Mining Bureau, pp. 11-15; Report, by William Irelan Jr., pp. 18-20; Hydraulic mining, p. 20; Drift mining, p. 20; River-bed mining, pp. 20-21; Vein mining, p. 21; Are the mines worked out?, p. 21; Silver mines, p. 22; Geological synopsis, pp. 22-23; Geology and mineralogy of Shasta County, by Harold W. Fairbanks, pp. 24-53, 1 map, 5 illus.; Notes on the geology and mineralogy of portions of Tehama, Colusa, Lake, and Napa Counties, by Harold W. Fairbanks, pp. 54-75, 3 illus.; Geology of San Diego County; also of portions of Orange and San Bernardino Counties, by Harold W. Fairbanks, pp. 76-120, 1 map, 8 illus.; Alameda County, by W. L. Watts, pp. 121-138; Amador County, by E. B. Preston, pp. 139-149; Butte County, by E. B. Preston, pp. 150-166, 1 map, 18 illus.; Calaveras County, by E. B. Preston, pp. 167-178; Colusa County, by W. L. Watts, pp. 179-188, 1 illus.; Contra Costa County, by W. L. Watts, pp. 189-194; Del Norte County, by W. L. Watts, pp. 195-199; El Dorado County, by E. B. Preston, pp. 200-209, 1 map, 3 illus.; Fresno County, by W. L. Watts, pp. 210-223, 5 illus.; Glenn County, by W. L. Watts, pp. 224-226; Humboldt County, by W. L. Watts, pp. 227-232, 2 illus.; Kern County, by W. L. Watts, pp. 233-238, 1 illus.; Lake County, by W. L. Watts, pp. 239-240; Lassen County, by E. B. Preston, pp. 241-242, 1 illus.; Los Angeles County, by W. H. Storms, pp. 243-248, 1 illus.; Marin County, by W. L. Watts, pp. 249-254; Mendocino County, by W. L. Watts, pp. 255-256; Merced County, by W. L. Watts, pp. 257-258; Monterey County, by E. B. Preston, pp. 259-262, 1 illus.; Nevada County, by J. B. Hobson and E. A. Wiltsee, pp. 263-318; Placer County, by W. L. Watts, pp. 319-322; Plumas County, by E. B. Preston, pp. 323-333, 1 illus.; Sacramento County, by W. L. Watts, pp. 334-336; San Bernardino County, by W. H. Storms, pp. 337-369, 11 illus.; San Benito County, by E. B. Preston, pp. 370-373; Santa Clara County, by W. L. Watts, pp. 374-375; San Diego County, by W. H. Storms, pp. 376-393, 7 illus.; San Joaquin County, by W. L. Watts, p. 394; Shasta County, by Wm. G. Hodson, pp. 395-399; Sierra County, by E. B. Preston, pp. 400-419, 3 illus.; Siskiyou County, by R. L. Dunn, pp. 420-452; Sonoma County, by W. L. Watts, pp. 453-463; Stanislaus County, by W. L. Watts, pp. 464-468; Sutter County, by W. L. Watts, pp. 469-471; Tehama County, by W. L. Watts, pp. 472-479; Trinity County, by R. L. Dunn, pp. 480-484; Tulare County, by W. L. Watts, pp. 485-492; Tuolumne County, by E. B. Preston, pp. 493-513, 3 illus.; Yolo County, p. 514; Yuba County, by W. L. Watts, pp. 515-516; Hydraulic ejectors, by E. A. Wiltsee, pp. 517-520, 1 illus.; A dissertation upon the origin, development, and establishment of American mining law, by A. H. Ricketts, pp. 521-574, with index, pp. 608-609; Index pp. 575-612.

The following are included with the reports, or may be obtained alone; Geological map of Shasta County, scale 1" = 4 mi., approx., free; Geological map of portions of San Diego, Orange, and San Bernardino Counties, scale 1" = 6 mi., free.

*Twelfth Report of the State Mineralogist (second biennial) two years ending September 15, 1894; J. J. Crawford, State Mineralogist. 1894. 541 pp., 10 pls., 4 maps, 98 illus.

Contains: Report of Trustees of State Mining Bureau, pp. 3-7; To the Trustees of the State Mining Bureau, by J. J. Crawford, pp. 8-20; Antimony, pp. 21-23; Argentiferous galena, pp. 23-26; Asphaltum and bituminous rock, pp. 26-33; Borax, pp. 34-35, 2 illus.; Chromic iron, pp.

35-38; Coal, pp. 38-65, 9 illus.; Copper, pp. 66-70; Gold, pp. 70-322 (includes Geology of a portion of Madera and Mariposa Counties, by W. H. Storms, pp. 165-176), 1 map, 27 illus.; Gypsum, pp. 323-325; Iron, pp. 325-327; Magnesite, p. 328; Manganese, pp. 329-330; Mineral springs, pp. 331-347; Natural gas, pp. 348-352; Petroleum, pp. 352-358; Quicksilver, pp. 358-372; Silver, pp. 372-378, 2 illus.; Structural materials, pp. 379-405, 7 illus.; Miscellaneous, pp. 406-411, 1 illus.; Method of determining the respective quantities of gold and quartz in quartz specimens, p. 412; Electric power transmission plants and the use of electricity in mining operations, by Thomas Haight Leggett, pp. 413-455, pls. 1-10, 18 illus.; Red Rock, Goler, and Summit mining districts, in Kern County, by Harold W. Fairbanks, pp. 456-458, 4 illus.; Auriferous conglomerate in California, by R. L. Dunn, pp. 459-471, 1 map; Preliminary report on the mineral deposits of Inyo, Mono, and Alpine Counties, by Harold W. Fairbanks, pp. 472-478, 2 illus.; Geology of a section of El Dorado County, by Harold W. Fairbanks, pp. 479-481; Ancient channel system of Calaveras County, by W. H. Storms, pp. 482-492, 2 maps, 7 illus.; Geology of northern Ventura, Santa Barbara, San Luis Obispo, Monterey, and San Benito Counties, by Harold W. Fairbanks, pp. 493-526, 18 illus.; Appendix, pp. 529-541 (including State Mining Bureau Act, pp. 529-532; Act establishing a system of mine bell signals, pp. 532-533; Act defining hydraulic mining, p. 534; Debris Commission Act, pp. 534-535; The Caminetti Law, pp. 535-541).

The following are included with the reports, or may be obtained alone: Map of auriferous conglomerate deposit, Siskiyou County, California, scale 1" = 1 mi., free. Map showing ancient channel system of Calaveras County, scale ⅝" = 1 mi., approx.; and The ancient channel system between San Andreas and Mokelumne Hill, scale 1⅝" = 1 mi.; two maps reprinted, price 25¢.

*Thirteenth Report (third biennial) of the State Mineralogist for the two years ending September 15, 1896; J. J. Crawford, State Mineralogist. 1896. 726 pp., 1 map, 94 illus.

Contains: Report of Trustees of State Mining Bureau, pp. 3-9; To the Trustees of the State Mining Bureau, by J. J. Crawford, pp. 10-30 (includes Quartz and drift mining, pp. 10-14; Hydraulic mining, pp. 14-18; Product of precious metals, p. 18; Petroleum, p. 19; Tin, p. 19; Reports, pp. 19-20; Appropriations, p. 20; Bureau fund, p. 20; County resources, p. 20; Geological Survey, pp. 21-23; Hydrography, p. 23; Department of Mines, pp. 23-24; Official visits, p. 24; Bulletins, pp. 24-27; Miscellaneous papers, pp. 27-28; California Miners' Association, pp. 28-29; Field assistants, pp. 29-30). Antimony, p. 31; Argentiferous galena, pp. 32-34; Asphalt and bituminous rock, pp. 35-45, 4 illus.; Borax, pp. 46-47; Chromic iron, pp. 48-50, 2 illus.; Coal, pp. 51-56; Copper, pp. 57-64, 1 illus.; Gold, pp. 64-503, 1 map, 29 illus.; Gypsum, pp. 503-504; Iron, p. 504; Magnesite, p. 505; Manganese, pp. 506-507; Mineral springs, pp. 508-524; Mining and irrigation ditches, artesian wells, etc., pp. 525-566, 3 illus.; Natural gas, pp. 567-569; Petroleum, pp. 570-593, 3 illus.; Quicksilver, pp. 594-604, 6 illus.; Silver, pp. 605-611; Structural materials, pp. 612-641, 7 illus.; Miscellaneous, pp. 642-646, 2 illus.; Appendix, pp. 647-726 (includes Preservation of structural timber, by John D. Isaacs, pp. 647-655, 1 illus.; Resumé of original researches, analyses, and refining methods of petroleum mainly from the southern counties of California, by Frederick Salathe, pp. 656-661; Oil as fuel in Los Angeles County, by W. L. Watts, pp. 662-664; Ore-deposits with special reference to the Mother Lode, by Harold W. Fairbanks, pp. 665-672; Electric-power transmission plants in California, by W. F. C. Hasson, pp. 673-678, 18 illus.; The sampling and measurement of ore-bodies in mine examinations, by Edmund B. Kirby, pp. 679-700, 13 illus.; Comstock ore-sampling, by John D. McGillivray, pp. 701-705; A water-power and compressed-air transmission plant for the North Star Mining Company, Grass Valley, California, by Arthur De Wint Foote, pp. 706-720, 4 illus.; The coming motive power, by Joseph W. Buell, from "Inventive Age." pp. 721-725; Congressional Act, making appropriations for the construction, repair, and preservation of certain public works on rivers and harbors, and for other purposes, p. 726, 36 illus.)

Fourteenth Report of the State Mineralogist (biennial period 1913-14); Fletcher Hamilton, State Mineralogist. 1916. 974 pp., 275 illus. Price $2.50.

Issued also in separate parts, as indicated below.

* (a) **Part 1,** The counties of Amador, Calaveras, and Tuolumne, by W. B. Tucker, pp. 1-172, 54 illus.

(b) **Part 2,** The counties of Colusa, Glenn, Lake, Marin, Napa, Solano, Sonoma, Yolo, by Walter W. Bradley, pp. 173-370, 71 illus. Price 50¢.

(c) **Part 3,** The counties of Del Norte, Humboldt, Mendocino, by F. L. Lowell, pp. 371-425, 16 illus. Price 35¢.

(d) **Part 4,** The counties of Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin, Stanislaus, by Walter W. Bradley, G. Chester Brown, F. L. Lowell, R. P. McLaughlin, pp. 427-634, 80 illus. Price 75¢.

(e) **Part 5,** The counties of San Diego, Imperial, by Frederick J. H. Merrill, pp. 635-743, 32 illus. Price 50¢.

* (f) **Part 6,** The counties of Shasta, Siskiyou, Trinity, by G. Chester Brown, pp. 745-925, 22 illus.; Index, pp. 929-974.

* Fifteenth Report of the State Mineralogist (biennial period 1915-16); Fletcher Hamilton, State Mineralogist. 1919. 990 pp., 15 pls., 3 maps, 398 illus.

Issued also in separate parts, as indicated below.

* (a) **Part 1,** Alpine County, Inyo County, Mono County, by Arthur S. Eakle, Emile Huguenin, R. P. McLaughlin, and Clarence A. Waring, pp. 1-175, 8 pls., 110 illus.

(b) **Part 2,** The counties of Butte, Lassen, Modoc, Sutter, and Tehama, by W. B. Tucker and Clarence A. Waring, pp. 179-266, 24 illus. Price 50¢.

* (c) **Part 3,** The counties of El Dorado, Placer, Sacramento, Yuba, by W. B. Tucker and Clarence A. Waring, pp. 267-459, 1 map, 81 illus.

* (d) **Part 4,** Los Angeles County, Orange County, Riverside County, by Frederick J. H. Merrill, pp. 461-589, 34 illus.

* (e) **Part 5,** The counties of Monterey, San Benito, San Luis Obispo, Santa Barbara, Ventura, by Walter W. Bradley, Emile Huguenin, C. A. Logan, and Clarence A. Waring, pp. 590-769, 3 pls., 61 illus.

* (f) **Part 6,** San Bernardino County, Tulare County, by H. C. Cloudman, Emile Huguenin, F. J. H. Merrill, and W. B. Tucker, pp. 771-954, 4 pls., 1 map, 79 illus.

Index, pp. 959-990.

* Sixteenth Report of the State Mineralogist; Fletcher Hamilton, State Mineralogist. 1920. 270 pp., 188 pp., 144 pp.; 40 illus., 12 illus., 21 illus.

Issued also in separate parts, as indicated below.

* (a) Mines and mineral resources of Nevada County, by Errol MacBoyle [December 1918] 1919, 270 pp., 40 illus.

(b) Mines and mineral resources of Plumas County, by Errol MacBoyle [December 1918] 1920, 188 pp., 12 illus. Price 50¢.

* (c) Mines and mineral resources of Sierra County, by Errol MacBoyle [December 1918] 1920, 144 pp., 21 illus.

Seventeenth Report of the State Mineralogist, 1920; Fletcher Hamilton, State Mineralogist. 1921. 562 pp., 8 pls., 62 illus. $2.50.

Mining in California during 1920. Contains: Introduction, by Fletcher Hamilton, pp. 3-4. *San Francisco field division*, by E. S. Boalich, pp. 5-261, pls. 1-3, 27 illus.: Part I, Scope of industry, pp. 7-16, Part II, San Francisco district by counties, pp. 17-562—Alameda County, by E. Huguenin and W. O. Castello, pp. 17-42, pl. 1, 2 illus.; Colusa County, pp. 43-47; Contra Costa County, by E. Huguenin and W. O. Castello, pp. 48-67, 6 illus.; Fresno County, pp. 68-73, 1 illus.; Glenn County, pp. 74-75; Kings County, pp. 76-77; Lake County, pp. 78-82; Madera County, pp. 83-84; Marin County, p. 85; Mariposa County, by W. O. Castello, pp. 86-143; Mendocino County, pp. 144-148; Merced County, pp. 149-150; Mono County, pp. 151-155; Monterey County, pp. 156-157; Napa County, pp. 158-161; Sacramento County, p. 161, San Benito County, p. 162;

San Francisco County, by E. Huguenin and W. O. Castello, pp. 163-165; San Joaquin County, p. 166; San Mateo County, by E. Huguenin and W. O. Castello, pp. 167-179, 4 illus.; Santa Clara County, by E. Huguenin and W. O. Castello, pp. 180-227, pls. 2-3, 13 illus.; Santa Cruz County, by E. Huguenin and W. O. Castello, pp. 228-241, 1 illus.; Solano County, pp. 242-247; Sonoma County, pp. 248-252; Stanislaus County, pp. 253-255; Sutter County, p. 256; Tulare County, pp. 257-260; Yolo County, pp. 260-261. *Los Angeles field division*, by W. B. Tucker, pp. 263-390, pls. 4-8, 20 illus.: Part I, Scope of industry, pp. 264-266, Part II, Los Angeles district, by counties, pp. 267-390—Imperial County, pp. 267-272; Inyo County, pp. 273-305, pls. 4-5, 10 illus.; Kern County, pp. 306-316, 1 illus.; Los Angeles County, pp. 317-322; Orange County, p. 323; Riverside County, pp. 324-332, 3 illus.; San Bernardino County, pp. 333-374, pls. 6-8, 5 illus.; San Diego County, pp. 375-383; San Luis Obispo County, pp. 384-386, 1 illus.; Santa Barbara County, pp. 387-389; Ventura County, p. 390. *Auburn field division*, by C. A. Logan, pp. 391-490, 15 illus.: Part I, Introductory, pp. 393-396, Part II, Auburn district, by counties, pp. 397-490—Alpine County, pp. 399-405, 3 illus.; Amador County, pp. 406-414, 4 illus.; Butte County, pp. 415-418; Calaveras County, pp. 419-424; El Dorado County, pp. 425-433, 1 illus.; Nevada County, pp. 434-440; Placer County, pp. 441-454, 1 illus.; Plumas County, pp. 455-473, 3 illus.; Sierra County, pp. 474-478; Tuolumne County, pp. 479-489, 3 illus.; Yuba County, p. 490. *Redding field division*, by C. McK Laizure, pp. 491-544: Part I, Scope of industry, pp. 493-501, Part II, Redding district, by counties, pp. 502-544—Del Norte County, pp. 502-503; Humboldt County, pp. 504-506; Lassen County, pp. 507-511; Modoc County, pp. 512-513; Shasta County, pp. 514-528; Siskiyou County, pp. 529-536; Tehama County, p. 537; Trinity County, pp. 538-544; Index, pp. 545-562.

*Eighteenth Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau during 1922; Fletcher Hamilton, State Mineralogist. 1923. 799 pp., 1 map, 72 illus.

Issued also in separate chapters, as indicated below.

* (a) Chapter 1, January 1922, pp. 1-40.

Contains: Redding field division, pp. 5-6; Auburn field division, by C. A. Logan, pp. 6-8; San Francisco field division, by C. McK Laizure, pp. 8-9; Los Angeles field division, by M. A. Newman, pp. 9-10; Oil and gas development, by R. E. Collom, p. 10; Placer gold resources, by Charles S. Haley, pp. 11-12; Non-metallic minerals of southern California, by M. A. Newman, pp. 13-14; Notes on the West Point district, Calaveras County, by C. A. Logan, pp. 15-21; Mining location on stock-raising lands, pp. 22-23; Statement to war minerals relief claimants, by Fletcher Hamilton, pp. 24-27.

* (b) Chapter 2, February 1922, pp. 42-93, 33 illus.

Contains: Shasta County, pp. 42-43; Trinity County, p. 43; by W. B. Tucker. El Dorado County, pp. 44-45; Nevada County, p. 45; Placer County, p. 45; by C. A. Logan. Contra Costa County, pp. 45-46; Napa County, p. 46; San Benito County, p. 46; San Mateo County, pp. 46-47; Tulare County, p. 47; by C. McK Laizure. Imperial County, pp. 47-48; Kern County, pp. 48-49; San Bernardino County, p. 49; San Diego County, p. 49; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 49-52; California's exhibit at the American Mining Congress Exposition, Chicago, Illinois, October 17-22, 1921, by Walter W. Bradley, pp. 54-58, 3 illus.; Genera of diatoms characteristic of marine and fresh waters, by G. Dallas Hanna and William M. Grant, pp. 59-76, 30 illus.; Change in mine assessment year, p. 77.

* (c) Chapter 3, March 1922, pp. 96-204.

Contains: Shasta County, p. 96; Siskiyou County, pp. 96-97; Trinity County, p. 97; by W. B. Tucker. Calaveras County, pp. 97-99; Tuolumne County, pp. 99-101; by C. A. Logan. Fresno County, pp. 101-102; Madera County, p. 102; Merced County, p. 102; Santa Clara County, pp. 102-103; Stanislaus County, p. 103; by C. McK Laizure. Imperial County, p. 104; Kern and San Bernardino Counties, pp. 104-106; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 106-108; Notes on iron ore occurrences in California, by E. S. Boalich, pp. 110-113; Economic minerals of the Avawatz Mountains, by W. B. Tucker, pp. 114-117, Agstone and its possibilities in California, by C. McK Laizure, pp. 118-121.

***(d) Chapter 4, April 1922, pp. 138-204, 3 illus.**

Contains: Shasta County, pp. 138-139; Siskiyou County, p. 139; Trinity County, p. 139; by W. B. Tucker. Nevada County, pp. 139-143; Sierra County, p. 143; by C. A. Logan. Alameda County, pp. 143-144; Contra Costa County, p. 144; Mariposa County, pp. 144-145; San Benito County, 145-146, 1 illus.; San Francisco County, p. 146; by C. McK Laizure. Kern County, pp. 146-148; San Bernardino County, pp. 148-149; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 150-151; Bibliography of coal in California, by E. S. Boalich, pp. 152-157; The metallurgy of platinum, by Louis Duparc (reprint) pp. 158-172, 1 illus.

***(e) Chapter 5, May 1922, pp. 206-254, 1 illus.**

Contains: Shasta County, pp. 206-207; Trinity County, p. 207; by W. B. Tucker. El Dorado County, pp. 208-210; Placer County, p. 211; by C. A. Logan. San Benito County, pp. 211-220, by E. S. Boalich. Kern County, pp. 220-221; Los Angeles County, p. 221; Riverside County, pp. 221-222; San Bernardino County, pp. 222-223; San Diego County, p. 223; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 224-225; Progress report on placer gold investigation, by Charles S. Haley, pp. 226-228; Memoranda on asphalt and bituminous sand deposits of California, by Lawrence Vander Leck, pp. 228-230; Non-metallic minerals of southern California [gypsum], by M. A. Newman, pp. 230-234; Mine assessment year, by C. McK Laizure, pp. 234-236, 1 illus.; Division of Minerals and Statistics, by Walter W. Bradley, pp. 239-245.

***(f) Chapter 6, June 1922, pp. 256-294, 2 illus.**

Contains: Shasta County, pp. 256-257; Siskiyou County, p. 257; Trinity County, pp. 257-258; by W. B. Tucker. Butte County, pp. 258-261; Nevada County, p. 261; Placer County, pp. 261-263; by C. A. Logan. Contra Costa County, p. 263; Glenn County, pp. 263-264; by C. McK Laizure. Los Angeles and Riverside Counties, pp. 264-265; San Bernardino County, pp. 265-266; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 266-269; Gold lodes of the East Fork mining district, Trinity County, by W. B. Tucker, pp. 270-273; Proposed method of mining oil sands, by M. A. Newman, pp. 273-275; California minerals exhibited during Shrine Convention, by Walter W. Bradley, pp. 275-278; Division of Minerals and Statistics, by Walter W. Bradley, pp. 281-286.

(g) Chapter 7, July 1922, pp. 295-352, 5 illus. Price 30¢.

Contains: Del Norte County, p. 295; Modoc County, p. 295; Shasta County, pp. 295-297; Siskiyou County, p. 297; Trinity County, pp. 297-298; by W. B. Tucker. Amador County, pp. 298-301; El Dorado County, p. 301; Placer County, pp. 301-302; by C. A. Logan. Madera County, pp. 303-307, by C. McK Laizure. Kern County, pp. 307-308; San Bernardino County, pp. 308-312; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 311-312; Silver lodes of the South Fork mining district, Shasta County, by W. B. Tucker, pp. 313-321, 2 illus.; Dry placers of southern California, by Charles S. Haley, pp. 321-324; Division of Minerals and Statistics, by Walter W. Bradley, pp. 327-344, 3 illus.

(h) Chapter 8, August 1922, pp. 353-403, 1 illus. Price 30¢.

Contains: Modoc County, p. 353; Shasta County, pp. 353-354; Siskiyou County, pp. 354-355; Tehama County, p. 355; Trinity County, p. 355; by W. B. Tucker. Alpine County, pp. 355-363, by C. A. Logan. Mariposa County, pp. 363-366, by E. S. Boalich. Los Angeles County, pp. 366-368; San Bernardino County, pp. 368-370; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 370-372; Progress report on placer gold investigation, by Charles S. Haley, pp. 373-374; Valuation of mining and oil property, by Fletcher Hamilton, pp. 375-379; Division of Minerals and Statistics, by Walter W. Bradley, pp. 382-397, 1 illus.

(i) Chapter 9, September 1922, pp. 405-491, 6 illus. Price 30¢.

Contains: Shasta County, pp. 405-413, 1 illus., by W. B. Tucker. Mono County, pp. 413-419; Napa County, p. 419; by E. S. Boalich. Inyo County, pp. 419-421; Imperial County, p. 421; Los Angeles County, p. 422; San Bernardino County, pp. 422-424; San Luis Obispo County, p. 424; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 425-426; Division of Minerals and Statistics, by Walter W. Bradley, pp. 429-485, 5 illus.

(j) Chapter 10, October 1922, pp. 493-593, 13 illus. Price 30¢.

Contains: Shasta County, pp. 493-495; Siskiyou County, pp. 495-496; Tehama County, p. 496; Trinity County, pp. 496-499; by W. B. Tucker. Sierra County [Quartz mining in Alleghany district], pp. 499-519, 2 illus., by C. A. Logan. Tulare County, pp. 519-538, 7 illus., by C. McK Laizure. Inyo County, p. 539; Kern County, p. 539; San Bernardino County, pp. 539-542; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 543-544; Radioactivity in thermal gases at The Geysers, Sonoma County, California, by Walter W. Bradley, pp. 545-550, 4 illus.; Tertiary sluice robbers, by Charles S. Haley, pp. 550-553; China clay in California, Part I, by Thomas Normile, pp. 554-557; Division of Minerals and Statistics, by Walter W. Bradley, pp. 560-587.

***(k) Chapter 11, November 1922, pp. 595-727, 1 map, 3 illus.**

Contains: Lassen County, p. 595; Shasta County, pp. 595-600, 1 illus.; Siskiyou County, p. 600; Trinity County, pp. 600-601; by W. B. Tucker. El Dorado County, p. 602; Placer County, pp. 602-603; Plumas County, pp. 604-606; Yuba County, pp. 606-608; by C. A. Logan. Napa County, pp. 608-610, 1 map, by C. McK Laizure. Inyo County, p. 611; San Bernardino County, pp. 611-614; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 615-617; California's mineral resources and the State Mining Bureau, by Fletcher Hamilton, pp. 618-627, 1 illus.; Division of Minerals and Statistics, by Walter W. Bradley, pp. 633-719.

(l) Chapter 12, December 1922, pp. 729-799, 4 illus. Price 30¢.

Contains: Shasta County, pp. 729-733, 2 illus.; Siskiyou County, p. 733; Trinity County, pp. 733-736, 1 illus.; by W. B. Tucker. Metal mining in the Auburn district, 1922, pp. 736-740, by C. A. Logan. Inyo County, pp. 740-741; Los Angeles County, p. 741; San Bernardino County, pp. 742-744; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 745-747; Ore treatment at the Belmont Shawmut mine, Tuolumne County, by C. A. Logan, pp. 748-750, 1 illus.; Bibliography of limestone deposits in California, by C. McK Laizure, pp. 751-754; Index, pp. 769-799.

*Nineteenth Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau; Fletcher Hamilton, Lloyd L. Root, State Mineralogists. 1923. 258 pp., 29 illus.

Issued also in separate chapters, as indicated below.

***(a) Chapter 1, Mining in California, January 1923, pp. 1-52, i-x.**

Contains: Redding field division, by W. B. Tucker, pp. 7-13. Auburn field division, by C. A. Logan, pp. 13-21. San Francisco field division, by C. McK Laizure, pp. 21-29. Los Angeles field division, by M. A. Newman, pp. 29-33; Oil field development operations, by R. E. Collom, pp. 33-37; Primary and secondary gold concentrations, by Charles S. Haley, pp. 38-40.

(b) Chapter 2, Mining in California, February 1923, pp. 53-87, i-x, 1 illus. Price 30¢.

Contains: Redding field division, by W. B. Tucker, pp. 55-59. Mother Lode region, by C. A. Logan, pp. 59-60. Monterey County, by C. McK Laizure, p. 60. Kern County, p. 61; San Bernardino County, pp. 61-64; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 65-66; Mining location on stock-raising lands, pp. 67-68; Limestone deposits of McCloud River, Shasta County, and their possible value for cement material, by W. B. Tucker, pp. 69-71, 1 illus.; The problem of exploiting the small mine and prospect, by C. A. Logan, pp. 72-76.

(c) Chapter 3, Mining in California, March 1923, pp. 88-133, i-ix. Price 30¢.

Contains: Shasta County, pp. 89-93; Siskiyou County, p. 93; Tehama County, p. 93; Trinity County, p. 94; by W. B. Tucker. Amador County, pp. 94-97, by C. A. Logan. Kern County, pp. 97-98; Los Angeles County, p. 98; San Bernardino County, pp. 98-100; San Diego County, p. 100; by M. A. Newman. Oil field development operations, by R. E. Collom, pp. 101-102; Notes on peat and its occurrence in California, by C. McK Laizure, pp. 103-107.

(d) Chapter 4, Mining in California, September 1923, pp. 134-244, i-ix, 28 illus. Price 30¢.

Contains: Lassen County, p. 135; Shasta County, pp. 135-137; Siskiyou County, pp. 138-139; Trinity County, pp. 139-140; by W. B. Tucker. Nevada County, p. 140; Placer County, pp. 140-141; El Dorado County, pp. 141-143; Amador County, p. 143; Calaveras County, pp. 143-144; Tuolumne County, pp. 144-145; by C. A. Logan. Mendocino County, by C. McK Laizure, pp. 145-154, 3 illus. Imperial County, pp. 154-155; Kern County, pp. 155-164, 1 illus.; Los Angeles County, pp. 164-165; Orange County, p. 165; San Bernardino County, pp. 165-173, by W. B. Tucker. Oil field development operations, by R. E. Collom, pp. 174-184; Clay deposits of the Alberhill Coal and Clay Company, by James H. Hill, pp. 185-210, 19 illus.; Oil shale in Santa Barbara County, California, by F. D. Gore, pp. 211-224, 5 illus.; Agricultural Minerals Act, pp. 225-226. Index, pp. 247-258.

*Twentieth Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau; Lloyd L. Root, State Mineralogist. 1924. 473 pp., 45 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, Mining in California, January 1924, pp. 1-72, i-ix, 10 illus. Price 30¢.

Contains: Amador County, pp. 1-3; Calaveras County, pp. 4-7; El Dorado County, pp. 8-9; Nevada County, pp. 9-12; Placer County, pp. 13-14; Plumas County, p. 14; Shasta County, pp. 15-17; Sierra County, pp. 17-18; Tuolumne County, pp. 19-23, 1 illus., by C. A. Logan. Metal mining, San Francisco field division, pp. 23-25; Non-metallic minerals, San Francisco field division, pp. 25-26; Napa County, pp. 26-28, 1 illus.; San Benito County, p. 28, 1 illus.; Santa Clara County, pp. 29-30, 1 illus.; Tulare County, pp. 30-33, by C. McK Laizure. Imperial County, p. 33; Inyo County, p. 33; Kern County, pp. 34-42, 1 map, 5 illus.; Los Angeles County, pp. 42-43; Orange County, pp. 43-45; Riverside County, pp. 45-46; San Bernardino County, pp. 46-49; San Diego County, pp. 49-50, by W. B. Tucker. Oil field development operations, by R. D. Bush, pp. 51-57.

(b) Chapter 2, Mining in California, April 1924, pp. 75-176, i-ix, 9 illus. Price 30¢.

Contains: Amador County, pp. 73-75; Calaveras County, pp. 76-80, 1 illus.; Mono County, p. 81; Placer County, pp. 81-82; Plumas County, pp. 82-83; Sacramento County, p. 83; Sierra County, p. 83; Yuba County, p. 84, by C. A. Logan. Contra Costa County, pp. 84-85; Lake County, p. 85; Mendocino County, pp. 86-87, 1 illus., by C. McK Laizure. Imperial County, pp. 87-91, 4 illus.; Los Angeles County, p. 91; San Bernardino County, pp. 92-97; Ventura County, pp. 97-98, by W. B. Tucker. Oil field development operations, by R. D. Bush, pp. 99-104; Oil and gas rights, by A. H. Ricketts, pp. 105-148; Note on andalusite from California, by Albert B. Peck, pp. 149-154, 1 illus.

***(c) Chapter 3, Mining in California, July 1924, pp. 177-353, i-ix, 12 illus.**

Contains: Amador County, pp. 177-178; Calaveras County, p. 178; El Dorado County, pp. 178-179; Nevada County, p. 179; Placer County, p. 179; Siskiyou County, pp. 179-183, by C. A. Logan. Alameda County, pp. 184-185, 1 illus., by C. McK Laizure. Inyo County, pp. 185-191, 3 illus.; Kern County, p. 191; Riverside County, pp. 191-196, 5 illus.; San Bernardino County, pp. 196-200, 3 illus., by W. B. Tucker. Oil field development operations, by R. D. Bush, pp. 201-207; Oil and gas rights, by A. H. Ricketts, pp. 208-245. Appendix: Regulations concerning oil and gas permits and leases, pp. 248-250; Oil and gas regulations, pp. 251-304; Notes on the law of mining locations and lands open to mining in California, by C. A. Logan, pp. 305-320; License required to handle mining property, by Edwin T. Keiser, pp. 321-322.

(d) Chapter 4, Mining in California, Octoebr 1924, pp. 355-473, 14 illus. Price 30¢.

Contains: Nevada County, pp. 355-362, 1 illus.; Sierra County, pp. 362-367, by C. A. Logan. Kern County, pp. 367-368; San Bernardino County, p. 368; San Diego County, pp. 368-374, by W. B. Tucker. Oil field

development operations, by R. D. Bush, pp. 375-380; Oil and gas rights, by A. H. Ricketts, pp. 381-415; Mineral exhibit at American Mining Congress convention, at Sacramento, California, by Walter W. Bradley, pp. 416-418; Copper resources of Shasta County, by W. B. Tucker, pp. 419-447, 13 illus. Index, pp. 461-473.

*Twenty-first Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau; Lloyd L. Root, State Mineralogist. 1925. 624 pp., 3 pls., 4 maps, 109 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, Mining in California, January 1925, pp. 1-133, i-ix, 24 illus. Price 30¢.

Contains: Sacramento County, by C. A. Logan, pp. 1-22, 10 illus.; Monterey County, by C. McK Laizure, pp. 23-57, 9 illus.; Orange County, by W. B. Tucker, pp. 58-71, 5 illus.; Oil field development operations, by R. D. Bush, pp. 72-76; Mining law, by A. H. Ricketts, pp. 77-121.

*** (b) Chapter 2, Mining in California, April 1925, pp. 134-274, i-ix, 37 illus.**

Contains: Calaveras County, by C. A. Logan, pp. 135-172, 5 illus.; Merced County, by C. McK Laizure, pp. 173-183, 4 illus.; San Joaquin County, by C. McK Laizure, pp. 184-200, 8 illus.; Stanislaus County, by C. McK Laizure, pp. 200-222, 12 illus.; Ventura County, by W. B. Tucker, pp. 223-245, 8 illus.; Oil field development operations, by R. D. Bush, pp. 246-250; California foundry sands, pp. 251-257.

*** (c) Chapter 3, Mining in California, July 1925, pp. 275-411, i-ix, 3 pls., 2 maps, 27 illus.**

Contains: Ancient channels of the Duncan Canyon region, Placer County, by C. A. Logan, pp. 275-280, 1 map; Del Norte County, by C. McK Laizure, pp. 281-284; Humboldt County, by C. McK Laizure, pp. 295-324, pls. 1-3, 1 map, 9 illus.; San Diego County, by W. B. Tucker, pp. 325-382, 18 illus.; Oil field development operations, by R. D. Bush, pp. 383-389; Dealers in gold-silver ores and bullion must take out licenses, pp. 390-396.

*** (d) Chapter 4, Mining in California, October 1925, pp. 413-624, i-ix, 2 maps, 21 illus.**

Contains: Siskiyou County, by C. A. Logan, pp. 413-498, 11 illus.; San Luis Obispo County, by C. McK Laizure, pp. 499-538, 2 maps, 4 illus.; Santa Barbara County, by W. B. Tucker, pp. 539-562, 6 illus.; Oil field development operations, by R. D. Bush, pp. 563-567; Directory of California foundries, pp. 568-572; Index, pp. 597-624.

*Twenty-second Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau; Lloyd L. Root, State Mineralogist. 1926. 610 pp., 5 maps, 129 illus.

Issued also in separate chapters, as indicated below.

*** (a) Chapter 1, Mining in California, January 1926, pp. 1-119, i-ix, 18 illus.**

Contains: Trinity County, by C. A. Logan, pp. 1-67, 10 illus.; Santa Cruz County, by C. McK Laizure, pp. 68-93, 8 illus.; Oil field development operations, by R. D. Bush, pp. 95-101; The so-called "mysterious white metal," by Frank Sanborn, pp. 102-107.

*** (b) Chapter 2, Mining in California, April 1926, pp. 120-312, i-ix, 4 maps, 47 illus.**

Contains: Shasta County, by C. A. Logan, pp. 120-216, 3 maps, 26 illus.; San Benito County, by C. McK Laizure, pp. 217-247, 7 illus.; Imperial County, by W. B. Tucker, pp. 248-285, 1 map, 14 illus.; Oil field development operations, by R. D. Bush, pp. 286-291; The Federal Revenue Act and the mining industry, pp. 292-297.

(c) Chapter 3, Mining in California, July 1926, pp. 313-396, i-ix, 1 map, 18 illus. Price 30¢.

Contains: Marin County, by C. McK Laizure, pp. 314-326, 5 illus.; Sonoma County, by C. McK Laizure, pp. 327-365, 1 map, 13 illus.; Oil field development operations, by R. D. Bush, pp. 366-369; Gas, gasoline, and petroleum, by A. H. Ricketts, pp. 370-372; Copper in California, by C. A. Logan, pp. 372-376.

***(d) Chapter 4, Mining in California, October 1926, pp. 397-610, i-ix, 46 illus.**

Contains: El Dorado County, by C. A. Logan, pp. 397-452, 5 illus.; Inyo County, by W. B. Tucker, pp. 453-530, 23 illus.; Oil field development operations, by R. D. Bush, pp. 531-537; The Minarets district, Madera County, by Walter W. Bradley, pp. 539-557, 18 illus.; Index, pp. 573-610.

*Twenty-third Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau; Lloyd L. Root, State Mineralogist. 1927. 456 pp., 1 map, 87 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, Mining in California, January 1927, pp. 1-130, i-ix, 1 map, 27 illus. Price 30¢.

Contains: Contra Costa County, by C. McK Laizure, pp. 2-31, 16 illus.; Mineral resources of Santa Catalina Island, by W. B. Tucker, pp. 32-39, 4 illus.; Oil field development operations, by R. D. Bush, pp. 40-43; Report of the Hydraulic Mining Commission upon the feasibility of the resumption of hydraulic mining in California, pp. 44-116, 1 map, 7 illus.

(b) Chapter 2, Mining in California, April 1927, pp. 131-234, i-ix, 24 illus. Price 30¢.

Contains: Amador County, by C. A. Logan, pp. 131-202, 20 illus.; Solano County, by C. McK Laizure, pp. 203-213, 4 illus.; Oil field development operations, by R. D. Bush, pp. 214-220; Manganese ore producers' committee, p. 221; Bibliography of clay deposits in California, pp. 221-222.

***(c) Chapter 3, Mining in California, July 1927, pp. 235-371, i-ix, 26 illus.**

Contains: Placer County, by C. A. Logan, pp. 235-286, 10 illus.; Los Angeles County, by W. B. Tucker, pp. 287-345, 16 illus.; Oil field development operations, by R. D. Bush, pp. 346-351; Ore Buyers' License Act, pp. 352-356.

(d) Chapter 4, Mining in California, October 1927, pp. 372-427, i-ix, 10 illus. Price 30¢.

Contains: Mono County, by W. B. Tucker, pp. 374-406, 10 illus.; Oil field development operations, by R. D. Bush, pp. 407-410; Department of Natural Resources Act, pp. 411-413; Index, pp. 429-456.

*Twenty-fourth Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau; Lloyd L. Root, Walter W. Bradley, State Mineralogists. 1928. 405 pp., 2 maps, 59 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, Mining in California, January 1928, pp. 1-70, i-ix, 4 illus. Price 30¢.

Contains: Tuolumne County, by C. A. Logan, pp. 3-53, 4 illus; Oil field development operations, by R. D. Bush, pp. 54-59.

***(b) Chapter 2, Mining in California, April 1928, pp. 71-172, i-ix, 11 illus.**

Contains: Mariposa County, by C. McK Laizure, pp. 72-153, 2 maps, 11 illus.; Oil field development operations, by R. D. Bush, pp. 154-158.

***(c) Chapter 3, Mining in California, July 1928, pp. 173-260, i-ix, 6 illus.**

Contains: Butte County, by C. A. Logan, pp. 173-210, 4 illus.; Tehama County, by Charles V. Averill, pp. 211-216, 2 illus.; Oil field development operations, by R. D. Bush, pp. 217-221; Quartz crystals, pp. 222-223; Notes on the law of mining locations and lands open to mining in California, by C. A. Logan, pp. 224-233; United States mining statutes, Title XXXII, Chapter 6, revised statutes, pp. 234-236; California statutes regarding location of mining claims, mill sites and assessment work, pp. 237-241.

(d) Chapter 4, Mining in California, October 1928, pp. 261-405, i-ix, 38 illus. Price 30¢.
Contains: Plumas County, by Charles V. Averill, pp. 261-316, 24 illus.; Madera County, by C. McK Laizure, pp. 317-345, 14 illus.; Oil field development operations, by R. D. Bush, pp. 346-352; Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 354-360; Index, pp. 375-405.

*Twenty-fifth Report of the State Mineralogist covering Mining in California and the activities of the State Mining Bureau; Walter W. Bradley, State Mineralogist. 1929. 588 pp., 5 maps, 147 illus.
Issued also in separate chapters, as indicated below.

***(a) Chapter 1, Mining in California, January 1929, pp. 1-149, i-ix, 1 map, 61 illus.**
Contains: Lassen County, by Charles V. Averill, pp. 2-9, 5 illus.; Modoc County, by Charles V. Averill, pp. 10-19, 7 illus.; Kern County, by W. B. Tucker, pp. 20-81, 1 map, 15 illus.; Oil field development operations, by R. D. Bush, pp. 82-87; Mammoth tusks found near Oroville, California, by G. Dallas Hanna, pp. 88-90, 2 illus.; Mineral pigment tests, pp. 91-92; American Manganese Products Association, p. 93; Some special methods and machines for recovery of gold and platinum in placer deposits, by C. McK Laizure, pp. 94-135, 32 illus.

***(b) Chapter 2, Mining in California, April 1929, pp. 150-281, i-x, 3 maps, 19 illus.**
Contains: Sierra County, by C. A. Logan, pp. 151-212, 3 maps; Napa County, by Charles V. Averill, pp. 213-245, 14 illus.; San Mateo County, by Sam P. Senior, Jr., pp. 245-259, 5 illus.; Oil field development operations, by R. D. Bush, pp. 260-265.

(c) Chapter 3, Mining in California, July 1929, pp. 282-416, i-x, 28 illus. Price 30¢.
Contains: Colusa County, by C. A. Logan, pp. 284-300; Fresno County, by C. McK Laizure, pp. 301-336, 19 illus.; Lake County, by Charles V. Averill, pp. 337-365, 9 illus.; Oil field development operations, by R. D. Bush, pp. 366-371; Ore Buyers License Act, pp. 372-377; Assessment work on mining claim within withdrawn areas, by A. H. Ricketts, pp. 378-386; Surface rights of a mineral locator within the national forests, by A. H. Ricketts, pp. 387-390; "Mine" and "mineral" defined for Mining Bureau Act, p. 391; "Division of Mines" amendment, p. 392.

***(d) Chapter 4, Mining in California, October 1929, pp. 417-588, 1 map, 39 illus.**
Contains: Glenn County, by Charles V. Averill, pp. 418-426, 5 illus.; Alameda County, by C. McK Laizure, pp. 427-456, 13 illus.; Mendocino County, by Charles V. Averill, pp. 456-467, 3 illus.; Riverside County, by W. B. Tucker and R. J. Sampson, pp. 468-526, 1 map, 18 illus.; Oil field development operations, by R. D. Bush, pp. 527-532; Index, pp. 553-588.

*Twenty-sixth Report of the State Mineralogist covering activities of the Division of Mines including the Geologic Branch; Walter W. Bradley, State Mineralogist. 1930. 535 pp., 4 maps, 101 illus.
Issued also in separate chapters, as indicated below.

(a) Chapter 1, Mining in California, January 1930, pp. 1-88, i-ix, 25 illus. Price 40¢.
Contains: Santa Clara County, by Herbert A. Franke, pp. 2-39, 13 illus.; Oil field development operations, by R. D. Bush, pp. 40-44; Barite in California, by Walter W. Bradley, pp. 45-57, 2 illus.; Mercury deposit in Coso Range, Inyo County, California, by Thor Warner, pp. 59-63, 4 illus.; Aerial photography and its importance to California geologists, by Leon T. Eliel, pp. 64-71, 6 illus.

***(b) Chapter 2, Mining in California, April 1930, pp. 89-183, i-ix, 2 maps, 5 illus.**

Contains: Nevada County, by C. A. Logan, pp. 90-137, 2 maps, 4 illus.; Geologic and economic mineral survey, by Olaf P. Jenkins, pp. 138-144; Oil field development operations, by R. D. Bush, pp. 145-147; Mineral paint materials in California, by Henry H. Symons, pp. 148-160, 1 illus.; Assessment work on mining claim within withdrawn areas, by A. H. Ricketts, pp. 161-163.

***(c) Chapter 3, Mining in California, July 1930, pp. 184-357, i-x, 2 maps, 35 illus.**

Contains: Yuba County, by C. A. Logan, pp. 186-201, 5 illus.; San Bernardino County, by W. B. Tucker and R. J. Sampson, pp. 202-325, 2 maps, 25 illus.; Oil field development operations, by R. D. Bush, pp. 326-329; Progress report, by Olaf P. Jenkins, pp. 330-333, 1 map; Commercial grinding plants in California, by Henry H. Symons, pp. 334-345, 5 illus.

The following is included with report, or may be obtained alone: Map of San Bernardino County showing locations of mines and mineral deposits, scale 1″ = 12 mi. Free.

(d) Chapter 4, Mining in California, October 1930, pp. 358-535, i-x, 35 illus. Price 40¢.

Contains: Butte County, by C. A. Logan, pp. 360-412, 10 illus.; Kings County, by Herbert A. Franke, pp. 413-423, 2 illus.; Tulare County, by Herbert A. Franke, pp. 423-471, 19 illus.; Geologic Branch, by Olaf P. Jenkins, pp. 472-474, 1 illus.; Preliminary report on the geology of southwestern Mono County, California, by Evans B. Mayo, pp. 475-482, 3 illus.; Oil field development operations, by R. D. Bush, pp. 483-487; Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 489-494; Our decreasing gold supply, by Alden Anderson, pp. 495-497; Index, pp. 513-535.

*Twenty-seventh Report of the State Mineralogist covering activities of the Division of Mines including the Geologic Branch; Walter W. Bradley, State Mineralogist. 1931. 582 pp., 8 pls., 8 maps, 130 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, Mining in California, January 1931, pp. 1-127, i-ix, 3 maps, 39 illus. Price 40¢.

Contains: Preliminary report on economic geology of the Shasta quadrangle, by Charles V. Averill, pp. 2-65, 1 map, 31 illus.; Record of progress by Federal departments, by Olaf P. Jenkins, pp. 67-73, 2 maps; Preparation of a new relief map of California, by H. A. Sedelmeyer, pp. 73-77, 2 illus.; Oil field development operations, by R. D. Bush, pp. 78-82; Beryllium and beryl, by Alice V. Petar, pp. 83-97; The new tariff and nonmetallic products, pp. 98-99; Crystalline talc, by Frank R. Wicks, pp. 100-104; Decorative effects in concrete, by Frank R. Wicks, pp. 105-111, 6 illus.

(b) Chapter 2, Mining in California, April 1931, pp. 128-244, i-x, 8 pls., 1 map, 15 illus. Price 40¢.

Contains: The Mountain Copper Company, Ltd., cyanide treatment of gossan, by Charles V. Averill, pp. 129-138, 4 illus.; Publication of papers on the geology of California, by Olaf P. Jenkins, p. 140; Stratigraphic significance of the Kreyenhagen shale of California, by Olaf P. Jenkins, pp. 141-186, 11 illus.; Diatoms and silicoflagellates of the Kreyenhagen shale, by G. D. Hanna, pp. 187-201, pls. A-E; Foraminifera of the Kreyenhagen shale, by C. C. Church, pp. 202-213, pls. A-C; Preliminary report of the geology of Santa Cruz Island, Santa Barbara County, California, by William W. Rand, pp. 214-219, 1 map; Oil field development operations, by R. D. Bush, pp. 200-221.

***(c) Chapter 3, Mining in California, July 1931, pp. 245-486, i-xviii, 3 maps, 53 illus.**

Contains: Yuba County, by C. A. Logan, pp. 246-261, 5 illus.; San Bernardino County, by W. B. Tucker and R. J. Sampson, pp. 262-401, 2 maps, 32 illus.; Progress report, by Olaf P. Jenkins, pp. 402-403; Oil field development operations, by R. D. Bush, pp. 404-406; Feldspar, silica,

andalusite and cyanite deposits in California, by R. J. Sampson and W. B. Tucker, pp. 407-458, 1 map, 14 illus.; A note on a deposit of andalusite in Mono County, California; its occurrence and technical importance, by J. A. Jeffery and C. D. Woodhouse, pp. 459-464, 2 illus.; Establishment of Trinity and Klamath River fish and game district affects mining, pp. 465-466.

(d) Chapter 4, Mining in California, October 1931, pp. 487-582, 1 map, 23 illus. Price 40¢.

Contains: Alpine County, by C. A. Logan, pp. 488-491; Progress report, by Olaf P. Jenkins, pp. 492-493; Geology of San Jacinto quadrangle south of San Gorgonio Pass, California, by Donald McCoy Fraser, pp. 494-540, 1 map, 23 illus.; Oil field development operations, by R. D. Bush, pp. 541-542; Notes on mining activity in Inyo and Mono Counties in July 1931, by W. B. Tucker, pp. 543-545; Index, pp. 563-582.

*Twenty-eighth Report of the State Mineralogist covering activities of the Division of Mines including the Geologic Branch; Walter W. Bradley, State Mineralogist. 1932. 429 pp., 7 pls., 2 maps, 158 figs.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, Mining in California, January 1932, pp. 1-101, i-xi, pls. 1-3, 45 figs. Price 40¢.

Contains: Economic mineral deposits of the San Jacinto quadrangle, by R. J. Sampson, pp. 3-11, pl. 1, 3 figs.; Contributions to the study of sediments, by Olaf P. Jenkins, pp. 12-13; Geology and physical properties of building stone from Carmel Valley, California, by E. Wayne Galliher, pp. 14-41, pl. 2, 25 figs.; Sediments of Monterey Bay, California, by E. Wayne Galliher, pp. 42-79, pl. 3, 17 figs.; Oil field development operations, by R. D. Bush, pp. 80-81; Sanbornite, a newly described mineral from California, by Walter W. Bradley, pp. 82-83; Sanbornite, a new barium disilicate mineral from Mariposa County, California, by Austin F. Rogers, p. 84; Topographic mapping program for California, by Everett N. Bryan, pp. 85-87; Tariff rate changed on feldspar, p. 87.

*** (b) Chapter 2, Mining in California, April 1932, pp. 102-255, i-xi, 1 map, 71 figs.**

Contains: Progress report, by Olaf P. Jenkins, p. 109; Oil field development operations, by R. D. Bush, pp. 110-111; Elementary placer mining methods and gold-saving devices, by C. McK Laizure, pp. 112-204, 1 map, 65 figs.; The pan, rocker, and sluice box, by Henry H. Symons, pp. 205-213, 5 figs.; Prospecting for vein deposits, by Frank Sanborn, pp. 214-218, 1 fig.; Selected bibliography on placer mining, by Herbert A. Franke, pp. 219-224; Placers of southern California, by R. J. Sampson, pp. 245-255.

***(c) Chapters 3-4, Mining in California, July-October 1932, pp. 256-429, pls. 2-5, 1 map, 42 figs.**

Contains: Ventura County, by W. B. Tucker and R. J. Sampson, pp. 247-277, 6 figs.; Current notes, by Olaf P. Jenkins, p. 278; Report accompanying geologic map of northern Sierra Nevada, by Olaf P. Jenkins, pp. 279-298, 1 map, 8 figs.; Notes on occurrence and age of fossil plants found in the auriferous gravels of Sierra Nevada, by Ralph W. Chaney, pp. 299-302, 2 figs.; Glacial and associated stream deposits of the Sierra Nevada, by Eliot Blackwelder, pp. 303-310, 5 figs., pl. 2; Jurassic and Cretaceous divisions in the Knoxville-Shasta succession of California, by Frank M. Anderson, pp. 311-328, 5 figs., pl. 3; Geology of a part of the Panamint Range, California, by F. M. Murphy, pp. 329-356, 12 figs., pl. 4; Mineral resources of a part of the Panamint Range, by R. J. Sampson, pp. 357-376, 4 figs., pl. 5; Oil field development operations, by R. D. Bush, pp. 377-381; Acquiring mining claims through tax title, pp. 383-384; Biennial Report of the State Mineralogist, by Walter W. Bradley, pp. 385-394, 1 fig.; Index, pp. 411-429.

The following was included with report, or sold separately:
* Geologic map of northern Sierra Nevada showing Tertiary river channels and Mother Lode belt, scale ½" = 1 mi.

*Twenty-ninth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1933. 411 pp., 8 pls., 103 figs.

Issued also in separate chapters, as indicated below.

*** (a) Chapters 1-2, California Journal of Mines and Geology, January-April 1933, pp. 1-268, i-xi, pls. 1-5, 78 figs.**

Contains: Gold deposits of the Redding and Weaverville quadrangles, by Charles V. Averill, pp. 2-73, pls. 1-2, 18 figs.; Current notes, by Olaf P. Jenkins, pp. 74-75; Geologic formations of the Redding-Weaverville districts, northern California, by Norman E. A. Hinds, pp. 76-122, pl. 3, 1 fig.; Economic geology of portions of Del Norte and Siskiyou Counties, northwesternmost California, by John H. Maxson, pp. 123-160, pl. 4, 26 figs.; Applications of geology to civil enginering, by Douglas Clark, pp. 161-173; The lakes of California, by William Morris Davis, pp. 175-236, pl. 5, 29 figs.; Oil field development operations, by R. D. Bush, pp. 237-238; Discovery of piedmontite in the Sierra Nevada, by Evans B. Mayo, pp. 239-243, 3 figs.; Suspension of assessment work, p. 243; Tracing buried-river channel deposits by geomagnetic methods, by Elmer W. Ellsworth, pp. 244-250, 2 figs.

The following is included with report, or may be obtained alone: Geologic map of the Redding and Weaverville quadrangles and the northwesternmost part of the Red Bluff quadrangle (gold mines located and described by Chas. V. Averill), scale 1" = 4 mi. Free.

(b) Chapters 3-4, California Journal of Mines and Geology, July-October 1933, pp. 268-411, pls. 6-8, 25 figs. Price $1.00.

Contains: Gold resources of Kern County, by W. B. Tucker and R. J. Sampson, pp. 271-339, pls. 6-8, 13 figs.; Oil field development operations, by R. D. Bush, pp. 341-347; Limestone deposits of the San Francisco region, by Edwin C. Eckel, pp. 348-361, 1 map, 7 figs.; Limestone weathering and plant associations of the San Francisco region, by Junea W. Kelly, pp. 362-367, 3 figs.; Booming, by C. McK Laizure, pp. 368-371, 1 fig.; Death Valley National Monument, California, by Herbert Hoover, pp. 371-372, 1 fig.; New state legislation, pp. 373-377; Index, pp. 397-411.

*Thirtieth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1934. 487 pp., 5 pls., 2 maps, 182 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1934, pp. 1-114, i-xiii, pls. 1-3, 48 illus. Price 60¢.

Contains: Current notes, by Olaf P. Jenkins, pp. 3-4, 1 illus.; Resurrection of early surfaces in the Sierra Nevada, by Olaf P. Jenkins, pp. 5-6; Geology and mineral resources of northeastern Madera County, California, by Homer D. Erwin, pp. 7-78, pl. 1, 41 illus.; Geology and mineral deposits of Laurel and Convict basins, southwestern Mono County, California, by Evans B. Mayo, pp. 79-88, pls. 2-3, 4 illus.; Oil field development operations, by R. D. Bush, pp. 89, 90; Notes on sampling as applied to gold quartz deposits, by Homer D. Erwin, pp. 91-99, 2 illus.

(b) Chapters 2-3, California Journal of Mines and Geology, April-July 1934, pp. 115-302, i-xiii, 1 map, 97 illus. Price $1.00.

Contains: Oil field development operations, by R. D. Bush, pp. 118-119; Elementary placer mining in California and notes on the milling of gold ores, by C. McK Laizure with contributions by H. H. Symons, Frank Sanborn, and H. A. Franke, pp. 121-289, 1 map, 97 illus.

*** (c) Chapter 4, California Journal of Mines and Geology, October 1934, pp. 303-487, pls. 4-5, 37 illus.**

Contains: Current mining developments in northern California, by Charles V. Averill, pp. 303-309; Current mining activity in southern California, by W. B. Tucker, pp. 310-327, 6 illus.; Current notes, by Olaf P. Jenkins, pp. 328-329, 1 illus.; Geology and mineral deposits of the Julian district, San Diego County, California, by Maurice Donnelly, pp. 331-370, pl. 4, 13 illus.; Geology and mineral deposits of the Elizabeth Lake quad-

rangle, California, by Edward C. Simpson, pp. 371-415, pl. 5, 15 illus.; Geologic features of the dry placers of the northern Mojave desert, by Carlton D. Hulin, pp. 416-426, 2 illus.; Oil field development operations, by R. D. Bush, pp. 427-429; Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 431-439; Government cannot challenge right to mining claims for failure to perform annual assessment work within withdrawn areas, pp. 440-443; Death Valley National Monument is now open to mining, pp. 444-445; Index, pp. 474-487.

The following was included with report, or could be purchased alone: * Geologic map of Elizabeth Lake quadrangle, scale 1" = 2 mi.

*Thirty-first Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1935. 583 pp., 7 pls., 4 maps, 142 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1935, pp. 1-110, i-xiv, pl. 1, 1 map, 42 illus. Price 60¢.

Contains: Review of gold mining in east-central California, 1934, by C. A. Logan, pp. 1-23, 9 illus.; Current mining activities in the San Francisco district with special reference to gold, by C. McK Laizure, pp. 24-48, 1 map, 10 illus.; Geological investigation of the clays of Riverside and Orange Counties, southern California, by J. Clark Sutherland, pp. 51-87, pl. 1, 23 illus.; Oil field development operations, by R. D. Bush, pp. 88-93; Information regarding mining loans by the Reconstruction Finance Corporation, pp. 95-99.

The following is included with report, or may be obtained alone: Map of Mariposa County showing principal gold mines, scale 1" = 3 mi. Free.

(b) Chapter 2, California Journal of Mines and Geology, April 1935, pp. 111-254, i-xiv, pls. 2-3, 43 illus. Price 60¢.

Contains: Current notes [Preliminary legend of rock formation units used on the new geologic map of California], by Olaf P. Jenkins, pp. 112-114; A geologic section across the southern Peninsular Range of California, by William J. Miller, pp. 115-142, pl. 2, 8 illus.; New technique applicable to the study of placers, by Olaf P. Jenkins, pp. 143-210, pl. 3, 35 illus.; Oil field development operations, by R. D. Bush, pp. 211-214; Grubstake permits, by Charles F. Johnson, pp. 215-219.

***(c) Chapter 3, California Journal of Mines and Geology, July 1935, pp. 255-400, i-xiv, pls. 4-5, 1 map, 15 illus.**

Contains: Mines and mineral resources of Siskiyou County, by Charles V. Averill, pp. 255-338, pl. 4, 13 illus.; Oil field development operations, by R. D. Bush, pp. 340-344; Dams for hydraulic mining debris, by Walter W. Bradley, pp. 345-367, pl. 5, 2 illus.; Leasing system as applied to metal mining, by W. O. Vanderburg, pp. 368-375; Mine financing in California, by Philip S. Matthews, pp. 376-381; New laws make radical change in mining rights, pp. 382-384.

The following is included with report, or may be obtained alone: Map of western portion of Siskiyou County showing locations of principal gold mines, scale 1½" = 5 mi. Free.

(d) Chapter 4, California Journal of Mines and Geology, October 1935, pp. 401-583, pls. 6-7, 2 maps, 42 illus. Price 60¢.

Contains: Mines and mineral resources of San Luis Obispo County, by Herbert A. Franke, pp. 402-461, 1 map, 16 illus.; Mineral resources of portions of Monterey and Kings County, by Herbert A. Franke, pp. 462-464; Mining activity at Soledad Mountain and Middle Buttes, Mojave mining district, Kern County, by W. B. Tucker, pp. 465-485, pls. 6-7, 11 illus.; Current notes, by Olaf P. Jenkins, p. 486; Geology of a portion of the Perris block, southern California, by Paul H. Dudley, pp. 487-506, 1 map, 10 illus.; Mineral resources of a portion of the Perris block, Riverside County, California, by R. J. Sampson, pp. 507-521, 5 illus.; Oil field development operation, by R. D. Bush, pp. 522-525; Index, pp. 556-583.

The following is included with report, or may be obtained alone: Geologic map, portion of Perris block, southern California, scale 1" = 2½ mi. Free.

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Thirty-second Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1936. 563 pp., 10 pls., 2 maps, 96 illus. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1936, pp. 1-124, i-xiv, 10 illus. Price 60¢.

Contains: Gold mines of Placer County, by C. A. Logan, pp. 7-96, 5 illus.; Borax Lake, California, by M. Vonsen and G. D. Hanna, pp. 99-108, 5 illus.; Oil field development operations, by R. D. Bush, pp. 109-112.

(b) Chapter 2, California Journal of Mines and Geology, April 1936, pp. 125-224, i-xiii, 1 map, 25 illus. Price 60¢.

Contains: Oil field development operations, by R. D. Bush, pp. 128-131; Geology, mining, and processing of diatomite at Lompoc, Santa Barbara County, California, by Henry Mulryan, pp. 133-166, 1 map, 23 illus.; Essentials in developing and financing a prospect into a mine, by Charles Will Wright, pp. 167-188; The gold-bearing veins of Meadow Lake district, Nevada County, by A. L. Wisker, pp. 189-204, 2 illus.

(c) Chapter 3, California Journal of Mines and Geology, July 1936, pp. 225-404, i-xiv, pls. 1-8, 1 map, 28 illus. Price 60¢.

Contains: Mines and mineral resources of Calaveras County, by C. A. Logan and Herbert A. Franke, pp. 226-364, pls. 1-8, 28 illus.; Current notes, by Olaf P. Jenkins, p. 366; Oil field development operations, by R. D. Bush, pp. 367-371; Placer mining in California with power shovels, by C. A. Logan, pp. 373-377; Assessment work on mining claims within withdrawn areas, pp. 378-381; Joshua Tree National Monument, pp. 382-383, 1 map; Cost of producing quicksilver at a California mine in 1931-1932, pp. 384-385; The age of mineral utilization, by John Wellington Finch, pp. 386-390.

(d) Chapter 4, California Journal of Mines and Geology, October 1936, pp. 405-563, pls. 1-2, 33 illus. Price 60¢.

Contains: Mineral resources of Lassen County, by Charles V. Averill and Homer D. Erwin, pp. 405-444, pls. 1-2, 14 illus.; Mineral resources of Modoc County, by Charles V. Averill, pp. 445-457, 5 illus.; Current notes, by Olaf P. Jenkins, p. 458; Mechanics of the Lone Mountain landslides, San Francisco, California, by William M. Cogan, pp. 459-474, 14 illus.; Oil field development operations, by R. D. Bush, pp. 475-479; Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 481-489; Properties and industrial applications of opaline silica, by John T. Thorndyke, pp. 490-494; Index, pp. 525-563.

*Thirty-third Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1937. 385 pp., 4 pls., 1 map, 62 illus.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1937, pp. 1-78, i-xiii, pl. 1, 12 illus. Price 60¢.

Contains: Source data of the geologic map of California, January 1937, by Olaf P. Jenkins, pp. 9-37, pl. 1; The geology of quicksilver ore deposits, by C. N. Schuette, pp. 38-50, 11 illus.; Oil field development operations, by R. D. Bush, pp. 51-54; Prospecting for lode gold, by E. D. Gardner, pp. 57-66.

(b) Chapter 2, California Journal of Mines and Geology, April 1937, pp. 79-172, i-xiii, pl. 2, 23 illus. Price 60¢.

Contains: Mineral resources of Plumas County, by Charles V. Averill, pp. 79-143, pl. 2, 13 illus.; Current notes, by Olaf P. Jenkins, pp. 145-146; Oil field development operations, by R. D. Bush, pp. 147-152; New placer mining debris law, pp. 154-155.

The following is included with report, or may be obtained alone: Map of Plumas County, showing areal geology and locations of principal mines, scale 1" = 3½ mi. Free.

(c) Chapter 3, California Journal of Mines and Geology, July 1937, pp. 173-261, i-xiii, pl. 3, 1 map, 16 illus. Price 60¢.

Contains: Mineral resources of Los Angeles County, by R. J. Sampson, pp. 173-213, 1 map, 8 illus.; Current notes, by Olaf P. Jenkins, p. 214, 1 illus.; Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County, by Gordon B. Oakeshott, pp. 215-249, pl. 3, 7 illus.

The following is included with report, or may be obtained alone: Map of Los Angeles County, California, showing the principal mines and oil fields, scale 1" = 4 mi. Free.

(d) Chapter 4, California Journal of Mines and Geology, October 1937, pp. 262-385, pl. 5, 21 illus. Price 60¢.

Contains: Mineral resources of the Resting Springs region, Inyo County, by R. J. Sampson, pp. 264-270, pl. 5, 2 illus.; Current notes, by Olaf P. Jenkins, pp. 270-272; Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California, by John C. Hazzard, pp. 273-339, 19 illus.; Native arsenic from Grass Valley, California, by W. D. Johnston, Jr., p. 340; Index, pp. 369-385.

*Thirty-fourth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1938. 669 pp., 7 pls., 115 illus.

Issued also in separate chapters, as indicated below.

***(a) Chapter 1, California Journal of Mines and Geology, January 1938, pp. 1-94, i-xiv, 13 illus.**

Contains: Mineral development and mining activity in southern California during the year 1937, by W. B. Tucker, pp. 8-19; Doing something about earthquakes, by R. R. Lukens, pp. 21-26, 6 illus.; Gold and petroleum in California, by Waldemar Lindgren, pp. 27-32; Gem minerals of California, by Francis J. Sperisen, pp. 34-78, 7 illus.

(b) Chapter 2, California Journal of Mines and Geology, April 1938, pp. 95-204, i-xv, pl. 1, 32 illus. Price 60¢.

Contains: Gold dredging in Shasta, Siskiyou and Trinity Counties, by Charles V. Averill, pp. 96-126, 16 illus.; Current notes, by Olaf P. Jenkins, pp. 127-129, 1 illus.; Geology of the central Santa Monica mountains, Los Angeles County, by E. K. Soper, pp. 131-180, pl. 1, 15 illus.; Marketing mica, by Paul M. Tyler, pp. 182-187.

The following is included with report, or may be obtained alone: Geologic map of Los Flores and Dry Canyon quadrangles and western part of Topanga Canyon quadrangle, Santa Monica Mountains, California, scale 2" = 1⅝ mi. Free.

(c) Chapter 3, California Journal of Mines and Geology, July 1938, pp. 205-366, i-xiv, pl. 2, 36 illus. Price 60¢.

Contains: Mineral resources of El Dorado County, by C. A. Logan, pp. 206-280, pl. 2, 18 illus.; Current notes, by Olaf P. Jenkins, pp. 281-282; Strategic minerals in California, by Charles White Merrill, pp. 283-291; Mineral highlights of California, by Walter W. Bradley, pp. 292-297; Submarine canyons off the California coast, by Francis P. Shepard, pp. 298-310, 9 illus.; The Mountain Copper Company, Ltd., cyanide treatment of gossan, by Charles V. Averill, pp. 312-330, 9 illus.; Use of ultra-violet light in prospecting for scheelite, by Ott F. Heizer, pp. 331-333; New State Lands Act of 1938, pp. 334-347; New amendment to the "Caminetti Act," 1938, p. 348.

The following is included with report, or may be obtained alone: Map of western portion of El Dorado County showing mining claims, scale 1" = 2 mi. Free.

***(d) Chapter 4, California Journal of Mines and Geology, October 1938, pp. 367-669, pls. 3-7, 34 illus.**

Contains: Mineral resources of Inyo County, by W. B. Tucker and R. J. Sampson, pp. 368-500, pls. 3-4, 33 illus.; Geology and ore deposits of the Darwin silver-lead mining district, Inyo County, California, by Vincent C. Kelley, pp. 503-562, pls. 5-7, 31 illus.; Sulphur deposits of Inyo County, California, by Edward D. Lynton, pp. 563-590, 14 illus.; Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 592-597, 1 illus.; Index, pp. 633-669.

The following is included with report, or may be obtained alone: Map of Inyo County, California, showing location of principal mines, scale 2½" = 15 mi. Free.

Thirty-fifth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1939. 552 pp., 4 pls., 86 illus. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) **Chapter 1, California Journal of Mines and Geology, January 1939, pp. 1-106, i-xv, pl. 1, 15 illus. Price 60¢.**

Contains: Mineral resources of San Diego County, by W. B. Tucker and Charles H. Reed, pp. 8-55, pl. 1, 7 illus.; Geology and oil possibilities of southwestern San Diego County, by Leo George Hertlein and U. S. Grant IV, pp. 57-78, 8 illus.; The prospect for "minor metals" and nonmetallic minerals, by John Wellington Finch, pp. 80-88; The right to mine, by Robert M. Searls, pp. 89-95.

The following is included with report, or may be obtained alone: Map of San Diego County showing location of principal mineral deposits, scale 1" = 3 mi. Free.

(b) **Chapter 2, California Journal of Mines and Geology, April 1939, pp. 107-214, i-xiv, pl. 2, 19 illus. Price 60¢.**

Contains: Mineral resources of Shasta County, by Charles V. Averill, pp. 108-191, pl. 2, 19 illus.; The public's interest in mine taxation, by A. G. Mackenzie, pp. 194-198.

The following is included with report, or may be obtained alone: Map of Shasta County showing locations of principal mineral deposits, scale 1" = 3 mi. Free.

(c) **Chapter 3, California Journal of Mines and Geology, July 1939, pp. 215-348, i-xvi, pls. 3-4, 26 illus. Price 60¢.**

Contains: Tertiary formations of northern Sacramento Valley, California, by Charles A. Anderson and R. Dana Russell, pp. 219-253, pl. 3, 14 illus.; Geology and oil possibilities of Caliente Range, Cuyama Valley, and Carrizo Plain, California, by J. E. Eaton, pp. 255-274, pl. 4, 5 illus.; Bibliography of the geology and mineral resources of California for the year 1937, prepared under the direction of Solon Shedd, with introduction by Olaf P. Jenkins, pp. 275-307; The Giant Goose Lake meteorite from Modoc County, California, by Earle G. Linsley, pp. 308-312, 3 illus.; Costs of trucking and packing ore in western gold-mining districts, by E. D. Gardner, pp. 314-330, 4 illus.; Strategic Minerals Act, pp. 331-333; Assessment work on mining claims for 1938-1939, p. 334; New mining legislation, 1939, pp. 335-337.

*(d) **Chapter 4, California Journal of Mines and Geology, October 1939, pp. 349-552, 26 illus.**

Contains: Current notes, by Olaf P. Jenkins, pp. 350-351; Quicksilver resources of California, by Alfred L. Ransome and John L. Kellogg, pp. 353-486, 26 illus.; Sulphate minerals at the Leviathan sulphur mine, Alpine County, California, by George L. Gary, pp. 488-489; Index, pp. 523-552.

The following reprint may be obtained alone: Quicksilver resources of California, by Alfred L. Ransome and John L. Kellogg, pp. 353-486, 26 illus. Price 50¢.

Thirty-sixth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1940. 494 pp., 5 pls., 127 illus. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) **Chapter 1, California Journal of Mines and Geology, January 1940, pp. 1-114, i-xvi, 20 illus. Price 60¢.**

Contains: Current mining activity in southern California, by W. B. Tucker and R. J. Sampson, pp. 9-82, 20 illus.; Notes on beryl with a qualitative analysis for beryllium, by George L. Gary, pp. 86-95; Strategic minerals investigation procedure followed by the U. S. Bureau of Mines, by John W. Finch, pp. 96-100.

(b) **Chapter 2, California Journal of Mines and Geology, April 1940, pp. 115-230, i-xvi, pl. 1, 43 illus. Price 60¢.**

Contains: Mineral resources of Mono County, by R. J. Sampson and W. B. Tucker, pp. 117-156, pl. 1, 11 illus.; General geology and ores of the Blind Spring Hill mining district, Mono County, California, by Alfred L.

Ransome, pp. 159-197, 28 illus.; Short report on the geological formations encountered in driving the Mono Craters tunnel, compiled by W. K. Gresswell, pp. 199-204, 3 illus.; Methods and costs of mining and concentrating chromite, by Alfred Burch and Samuel H. Dolbear, pp. 205-210, 1 illus.

The following is included with report, or may be obtained alone: Map of Mono County showing location of principal mining properties, scale 1″ = 6 mi. Free.

(c) Chapter 3, California Journal of Mines and Geology, July 1940, pp. 231-320, i-xvi, pls. 2-3, 10 illus. Price 60¢.

Contains: Economic mineral deposits of the Newberry and Ord Mountains, San Bernardino County, by W. B. Tucker and R. J. Sampson, pp. 232-254, 1 illus.; Current notes, by Olaf P. Jenkins, pp. 255-256; Geology of the Newberry and Ord Mountains, San Bernardino County, California, by Dion L. Gardner, pp. 257-292, pl. 2, 9 illus.; Notes on the geology of a portion of the Calico Mountains, San Bernardino County, California, by Homer D. Erwin and Dion L. Gardner, pp. 293-304, pl. 3; Study of chrome process aided by Martin Dennis Company, p. 305.

(d) Chapter 4, California Journal of Mines and Geology, October 1940, pp. 321-494, pls. 2-3, 54 illus. Price 60¢.

Contains: Mineral resources of the Kernville quadrangle, by W. B. Tucker and R. J. Sampson, pp. 322-333, 1 illus.; Strategic problems of the mineral industry in California, by Olaf P. Jenkins, pp. 335-341; Descriptive geology of the Kernville quadrangle, California, by William J. Miller and Robert W. Webb, pp. 343-378, pl. 2, 31 illus.; Geology of the Big Blue group of mines, Kernville, California, by John W. Prout Jr., pp. 379-421, pl. 3, 22 illus.; Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 423-431; Strategic tax exemption, p. 432; Federal loans for strategic minerals, an Act, pp. 432-433; Index, pp. 481-494.

The following is included with report, or may be obtained alone: Geologic map of Kernville quadrangle, California, scale 1″ = 2 mi. Free.

Thirty-seventh Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1941. 656 pp., 3 pls., 1 map, 99 illus. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1941, pp. 1-200, i-xvi, pl. 1, 50 illus. Price 60¢.

Contains: Mineral resources of Trinity County, by Charles V. Averill, pp. 8-89, pl. 1, 19 illus.; Current notes, by Olaf P. Jenkins, p. 90; Strategic minerals procurement, by Charles W. Merrill, pp. 91-100; Geological investigation of the chromite deposits of California, by John Eliot Allen, pp. 101-167, 31 illus.; United States Supreme Court renders far-reaching decision on power permits on "navigable" streams, pp. 169-183; Securities and Exchange Commission, Securities Act of 1933, pp. 184-189.

The following is included with report, or may be obtained alone: Map of Trinity County showing locations of principal mineral deposits, scale 1″ = 4 mi. Free.

(b) Chapter 2, California Journal of Mines and Geology, April 1941, pp. 201-372, i-xvii, 24 illus. Price 60¢.

Contains: Current notes, by Olaf P. Jenkins, pp. 202-203; Geological progress of the California State Division of Mines, 1930 to 1940, by Olaf P. Jenkins, pp. 205-217; California earthquakes of the Mission period, 1769-1838, by Robert F. Heizer, pp. 219-223; Occurrence of scheelite in Idaho-Maryland mines at Grass Valley, California, by Rollin Farmin, p. 224; Tungsten resources of California, by John F. Partridge Jr., pp. 225-326, 22 illus.; Dragline dredging in Siskiyou County, by Charles V. Averill, pp. 328-331, 2 illus.; Marketing talc, pyrophyllite, and ground soapstone, by Bertrand L. Johnson, pp. 332-341; Manganese, by George L. Gary, pp. 342-344; Magnesite, by George L. Gary, pp. 345-347.

(c) Chapter 3, California Journal of Mines and Geology, July 1941, pp. 373-496, i-xvii, pls. 2-3, 1 map, 11 illus. Price 60¢.

Contains: Mineral resources of Nevada County, by C. A. Logan, pp. 374-408, pls. 2-3, 1 map, 6 illus.; Mining methods and costs of the Lava Cap Gold Mining Corporation, Nevada City, California, by John W.

Chandler, pp. 409-436, 4 illus.; The price of gold, by Arthur B. Foote, pp. 437-468, 1 illus.; Current notes, by Olaf P. Jenkins, pp. 469-470; History of the names cobalt and nickel, by W. B. Winston, pp. 472-474; Aluminum, by George L. Gary, pp. 475-477; Quartz, by George L. Gary, pp. 478-482; New mining laws, an Act to amend Sec. 2313 of the Public Resources Code, pp. 483-485.

The following are included with report, or may be obtained alone: Large-scale map, Grass Valley and Nevada City district, showing mining claims, scale 1⅝" = 1 mi., free; Map of western portion Nevada County, California, showing mining claims, scale 2" = 3 mi., free.

(d) Chapter 4, California Journal of Mines and Geology, October 1941, pp. 497-656, 14 illus. Price 60¢.

Contains: Mineral resources of Humboldt County, by Charles V. Averill, pp. 499-528, 7 illus.; Tin in California, by Richard J. Segerstrom, pp. 531-557, 4 illus.; California quicksilver program of the Federal Geological Survey, by Edwin B. Eckel, pp. 558-563; Recent developments in the tungsten resources of California, by W. B. Tucker and R. J. Sampson, pp. 565-588, 3 illus.; New manganese and chrome ore specifications and prices, pp. 589-592; Does scheelite always fluoresce?, by George L. Gary, p. 593; Bentonite, by George L. Gary, pp. 594-596; Index, pp. 627-656.

Thirty-eighth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1942. 414 pp., 9 pls., 1 map, 100 figs. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1942, pp. 1-104, i-xvii, 19 figs. Price 60¢.

Contains: Mines and mineral resources of Sierra County, by Charles V. Averill, pp. 7-67, 17 figs.; Chromium, by Charles V. Averill, pp. 70-93, 2 figs.

(b) Chapter 2, California Journal of Mines and Geology, April 1942, pp. 105-220, i-xvii, pls. 1-3, 30 figs. Price 60¢.

Contains: Mineral resources of Imperial County, by R. J. Sampson and W. B. Tucker, pp. 105-145, pl. 1, 11 figs.; Geology and mineral deposits of the Cargo Muchacho Mountains, Imperial County, California, by Paul C. Henshaw, pp. 147-196, pls. 2-3, 15 figs.; Imperial carbon-dioxide gas field, by James C. Bransford, pp. 198-201, 4 figs.; The legendary "white metal" and its "ore", by C. W. Davis, pp. 202-205; Mine assessment work suspended on claims within withdrawn areas, an Act of Congress, p. 206.

The following is included with report, or may be obtained alone: Map of Imperial County showing locations of principal mineral deposits, scale 2" = 15 mi. Free.

(c) Chapter 3-4, California Journal of Mines and Geology, July-October 1942, pp. 221-414, pls. 4-9, 1 map, 51 figs. Price $1.20.

Contains: Hot springs deposits of the Coso Mountains, by H. J. Fraser, H. D. B. Wilson, and N. W. Henry, pp. 223-242, pls. 4-6, 1 map, 16 figs.; Contact-metamorphic rocks of the Twin Lakes region, Fresno County, California, by Charles W. Chesterman, pp. 243-282, pl. 7, 32 figs.; Tungsten deposits of the Confidence mining district, Tuolumne County, California, by James M. Little, pp. 283-290, pl. 8; Geology of the Welsh tungsten deposits, Madera County, California, by James M. Little, pp. 291-294, pl. 9; Ghost Canyon tungsten claims, Madera County, California, by James M. Little, pp. 295-302, 3 figs.; Tabulation of tungsten deposits of California to accompany economic mineral map No. 4, prepared under the direction of Olaf P. Jenkins, pp. 303-364; Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 367-378; Index, pp. 399-414.

The following is included with report, or may be purchased alone: Outline geologic map of California showing locations of tungsten properties (Economic mineral map of California No. 4—Tungsten), scale 1:1,000,000, price 60¢.

Thirty-ninth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1943. 609 pp., 8 pls., 123 figs. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1943, pp. 1-110, i-xvi, pls. 1-2, 23 figs. Price 60¢.

Contains: Mines and mineral resources of Santa Cruz County, by Henry G. Hubbard, pp. 11-52, pls. 1-2, 21 figs.; Discoveries in the strategic minerals, San Francisco field district, by C. McK Laizure, pp. 53-57; Current notes on activity in the strategic minerals, Los Angeles field district, by W. B. Tucker and R. J. Sampson, pp. 58-70; Current notes on activity in the strategic minerals, Sacramento field district, by Charles V. Averill, pp. 71-76, 2 figs.; Current notes on activity in the strategic minerals, Redding field district, by J. C. O'Brien, pp. 77-84; Current mining activity in Plumas County, by C. A. Logan, pp. 85-87; Current notes [Recent publications on strategic minerals by the U. S. Geological Survey], by Olaf P. Jenkins, pp. 88-89; Department of the Interior information service [Chromite deposits on North Elder Creek, Tehama County; Chromite deposits of McGuffy Creek area, Siskiyou County; Fairview and Ladd chromite deposits, Siskiyou County; Chromite deposits near San Luis Obispo; Manganese deposits of the Ladd-Buckeye area near Tracy; Quicksilver deposits of the New Idria district; New methods for determination of molybdenum in scheelite], by United States Geological Survey, pp. 90-102.

The following is included with report, or may be obtained alone: Map of Santa Cruz County (showing location of principal mineral properties), scale 1" = 3 mi. Free.

(b) Chapter 2, California Journal of Mines and Geology, April 1943, pp. 111-292, i-xvi, pls. 3-4, 44 figs. Price 60¢.

Contains: Manganese discovery in San Mateo County, by Henry G. Hubbard, p. 117, 1 fig.; Current mining activity in southern California, by W. B. Tucker and R. J. Sampson, pp. 118-138, 2 figs.; Current notes on activity in the strategic minerals, Sacramento field district, by Charles V. Averill, pp. 139-141, 1 fig.; Clerbus-Mae tungsten prospect, Trinity County, by J. C. O'Brien, p. 142; Current notes, by Olaf P. Jenkins, pp. 143-144, 1 fig.; Mylonites in the eastern San Gabriel Mountains, by Raymond M. Alf, pp. 145-151, 6 figs.; Geology of the Sierra Nevada northeast of Visalia, Tulare County, California, by Cordell Durrell, pp. 153-168, pls. 3-3A; Tungsten deposits northeast of Visalia, by William O. Jenkins, pp. 169-182, 3 figs.; Geology of the San Benito quadrangle, California, by Ivan F. Wilson, pp. 183-270, pl. 3, 30 figs.; Lithium, by George L. Gary, pp. 276-278; Quartz, by W. B. Winston, pp. 278-284.

The following is included with report, or may be purchased alone: Geologic map of the San Benito quadrangle, California, scale 1:62,500, pl. 3. Price 40¢.

(c) Chapter 3, California Journal of Mines and Geology, July 1943, pp. 293-420, i-xvii, 25 figs. Price 60¢.

Contains: Carbon dioxide gas occurrences in Mendocino and northern Sonoma Counties, by Henry G. Hubbard, pp. 301-309, 8 figs.; Current notes on activity in the strategic minerals, Sacramento field district, by Charles V. Averill, pp. 311-322, 4 figs.; Current notes on the activity in the strategic minerals, Redding field district, by J. C. O'Brien, pp. 323-330; Crestmore minerals, by A. O. Woodford, pp. 333-365, 7 figs., The isometrograph as developed and used at the New Idria quicksilver mine, by J. McLaren Forbes, pp. 367-376, 6 figs.; Discussion of Bulletin 118—notes relating to Sutter (Marysville) Buttes gas field, by Walter Stalder, pp. 377-381; The sillimanite group of minerals, by Joseph A. Jeffery, pp. 383-390; New federal and state legislation affecting mining, pp. 391-409.

*(d) Chapter 4, California Journal of Mines and Geology, October 1943, pp. 421-609, pls. 5-8, 31 figs.

Contains: Mineral resources of San Bernardino County, by W. B. Tucker and R. J. Sampson, pp. 427-549, pls. 5-7, 27 figs.; Current notes on activity in the strategic minerals, Sacramento field district, by Charles V. Averill, pp. 551-559, 4 figs.; Current notes, by Olaf P. Jenkins, pp. 560-561, pl. 8; Geologic map of a portion of the Foothill copper belt, Calaveras County, California, by Stanford Geological Survey, pl. 8; Index, pp. 593-609.

The following is included with report, or may be obtained alone: Map of San Bernardino County, California, showing locations of mines and mineral deposits, scale 1" = 8 mi. Free.

Fortieth Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1944. 509 pp., 12 pls., 8 maps, 97 figs. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1944, pp. 1-162, pls. 1-7, 43 figs. Price 60¢.

Contains: Geology of Palm Springs-Blythe strip, Riverside County, California, by William J. Miller, pp. 11-72, pls. 1-4, 23 figs.; Geology of parts of the Barstow quadrangle, San Bernardino County, California, by William J. Miller, pp. 73-112, pls. 5-6, 18 figs.; Geology of the Needles-Goffs region, San Bernardino County, California, by William J. Miller, pp. 113-129, pl. 7, 1 fig.; Airox concrete aggregate, by S. G. Dolman, pp. 131-133, 1 fig.; Marketing magnesite and allied products, by Charles L. Harness and Nan C. Jensen, pp. 134-149.

(b) Chapter 2, California Journal of Mines and Geology, April 1944, pp. 163-282, i-xvii, pls. 8-10, 32 figs. Price 60¢.

Contains: Status of topographic and geologic mapping in California, by Olaf P. Jenkins, pp. 171-176, pl. 8; Geology of the Jamesburg quadrangle, Monterey County, California, by William Morris Fiedler, pp. 177-250, pls. 9-10, 32 figs.

The following are included with report, or may be obtained alone: Map of California showing progress in topographic quadrangles and geologic maps, scale 1" = 40 mi. (approx.); and Map of California showing distribution of mineral deposits, scale 1" = 40 mi. (approx.), free. Geologic map of the Jamesburg quadrangle, Monterey County, California, scale 1:62,500; and Structure sections across Jamesburg quadrangle, Monterey County, California, price 40¢.

(c) Chapter 3, California Journal of Mines and Geology, July 1944, pp. 283-392, i-xvii, 8 maps, 12 figs. Price 60¢.

Contains: Progress on revision of Bulletin 113, Minerals of California, by Joseph Murdoch and Robert W. Webb, p. 290; Mines and quarries of the Indians of California, by Robert F. Heizer and Adan E. Treganza, pp. 291-359, 8 maps, 11 figs.; Fluorescent minerals in the exhibit of the State Division of Mines, by Henry H. Symons, pp. 361-368, 1 fig.; Fluorescent minerals used in lighting and elsewhere, by Oliver C. Ralston and A. George Stern, pp. 369-380.

(d) Chapter 4, California Journal of Mines and Geology, October 1944, pp. 393-500, pls. 11-12, 9 figs. Price 60¢.

Contains: Biennial report of the State Mineralogist, by Walter W. Bradley, pp. 401-408; Pellet phosphorite from Carmel Valley, Monterey County, California, by Austin F. Rogers, pp. 411-421, 6 figs.; Geology of the quartz-crystal mines near Mokelumne Hill, Calaveras County, California, by Cordell Durrell, pp. 423-433, pls. 11-12, 3 figs.; Strategic mica, by G. Richards Gwinn, pp. 435-447; Additional note on strategic mica, by Charles V. Averill, pp. 448-449; Marketing vermiculite, by G. Richards Gwinn, pp. 450-459; An Act providing for the suspension of certain requirements relating to work on tunnel sites, p. 460; An Act regulating mineral, oil, and gas brokers and salesmen, pp. 461-470; Index, pp. 501-509.

Forty-first Report of the State Mineralogist; Walter W. Bradley, State Mineralogist. 1945. 401 pp., 50 pls., 12 figs. Price, cloth-bound volume, $3.00.

Issued also in separate chapters, as indicated below.

(a) Chapter 1, California Journal of Mines and Geology, January 1945, pp. 1-54, i-xviii, pls. 1-5, 3 figs. Price 60¢.

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(b) Chapter 2, California Journal of Mines and Geology, April 1945, pp. 55-110, i-xviii, pls. 6-22, 2 figs. Price 60¢.

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(c) Chapter 3, California Journal of Mines and Geology, July 1945, pp. 111-220, i-xviii, pls. 23-35. Price 60¢.

Contains: Mineral resources of Riverside County, by W. B. Tucker and R. J. Sampson, pp. 121-182, pls. 23-35; Recent legislation affecting mining, pp. 183-191; Carbon, by W. B. Winston, pp. 196-208; Fluorspar, by W. B. Winston, pp. 209-212.

The following is included with report, or may be obtained alone: Map of Riverside County, California, showing locations of mines and mineral deposits, scale 1″ = 6 mi. Free.

(d) Chapter 4, California Journal of Mines and Geology, October 1945, pp. 221-401, pls. 36-50, 7 figs. Price 60¢.

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Forty-second Report of the State Mineralogist; Walter W. Bradley, W. B. Tucker, State Mineralogists. 1946. 430 pp., 55 pls., 40 figs. Price, cloth-bound volume, $3.00.

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(b) Chapter 2, California Journal of Mines and Geology, April 1946, pp. 74-164, i-xviii, pls. 8-22, 17 figs. Price 60¢.

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trict, Sonoma County, California, by Edgar H. Bailey, pp. 199-230, frontispiece, pls. 30-33, 3 figs.; Quicksilver deposits of eastern Mayacmas district, Lake and Napa Counties, California, by Robert G. Yates and Lowell S. Hilpert, pp. 231-286, pls. 29, 34-47, 8 figs.; Minerals at "The Geysers," Sonoma County, California, by M. Vonsen, pp. 287-293, pl. 48; Observations at "The Geysers," Sonoma County, California, by Walter W. Bradley, pp. 295-298, pls. 49-50.

The following are included with report, or may be obtained alone: Map of Tehama County, California, showing locations of principal mineral deposits, scale 1" = 6 mi., approx.; free. Geologic map and sections of the Mayacmas quicksilver district, Sonoma, Lake, and Napa Counties, scale 1" = 1 mi., price 50¢.

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California Journal of Mines and Geology, volume 44. 1948.

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BULLETINS (B)

*1. A description of the desiccated human remains in the California State Mining Bureau, by Winslow Anderson. 1888. 41 pp., 6 illus.

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*6. California gold mill practices, by Ed B. Preston. 1895. 85 pp., 54 illus.

*7. Mineral production of California, by counties, for the year 1894, by Charles G. Yale. 1895. Tabulated sheet.

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*9. Mine drainage, pumps, etc., by Hans C. Behr. 1896. 210 pp., 206 figs.

*10. A bibliography relating to the geology, palaeontology, and mineral resources of California, by Anthony W. Vodges. 1896. 121 pp.

*11. Oil and gas yielding formations of Los Angeles, Ventura, and Santa Barbara Counties, by W. L. Watts. 1897. 94 pp., 35 figs.

*12. Mineral production of California, by counties, for 1896, by Charles G. Yale. 1897. Tabulated sheet.

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*20. Synopsis of general report of the California State Mining Bureau, by W. L. Watts. 1901. 21 pp.

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*22. Mineral production of California for fourteen years, by Charles G. Yale. 1900. Tabulated sheet.

*23. The copper resources of California. 1902. 282 pp., 77 illus.
The following was included with bulletin: * Map of California showing the approximate location of the principal copper deposits of the state. 1902.

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(b) **Part 2, Geology of California and the occurrence of oil and gas, pp. 81-276, pls. 2-6, figs. 36-115, containing the following chapters:** *Chapter 4, Introduction to the geology, pp. 82-97, 1 map, figs. 36-45, composed of* Geomorphic provinces of California, by Olaf P. Jenkins, pp. 83-88, figs. 36-38; California relief map, 1930, showing geomorphic provinces, by H. A. Sedelmeyer, p. 84, fig. 36; Salient geologic events in California and their relationship to mineral deposition, by Olaf P. Jenkins, pp. 89-94, figs. 39-43; Position of the California oil fields as related to geologic structure, by Ralph D. Reed, pp. 95-97, figs. 44-45. *Chapter 5, Geologic history and structure, pp. 98-163, pl. 2, figs. 46-59B composed of* California's record in the geologic history of the world, by Ralph D. Reed, pp. 99-118, figs. 46-55; Geologic history and structure of the central Coast Ranges of California, by N. L. Taliaferro, pp. 119-163, figs. 56-59B, pl. 2. *Chapter 6, Paleontology and stratigraphy, pp. 164-207, pls. 3-4, figs. 60-87B composed of* Characteristic fossils of California, by G. Dallas Hanna and Leo George Hertlein, pp. 165-182, figs. 60-67; Descriptions of foraminifera, by C. C. Church, p. 182; Synopsis of the later Mesozoic in California, by Frank M. Anderson, pp. 183-186, figs. 68-71; Notes on Tertiary correlation, by Bruce L. Clark, pp. 187-191, fig. 72; Index to township and range system of California, p. 192, fig. 73; Eocene formaminiferal correlations in California, by Boris Laiming, pp. 193-198, figs. 74-83; Sequence of Oligocene formations of California, by Lesh C. Forrest, pp. 199-200, pl. 3, fig. 84; Correlation

chart of the Miocene of California, by Robert M. Kleinpell, p. 200, pl. 4; Pliocene correlation chart, by U. S. Grant IV and Leo George Hertlein, pp. 201-202, fig. 85; The Pleistocene in California, by J. E. Eaton, pp. 203-207, figs. 86-87B. *Chapter 7, Occurrence of oil, pp. 208-276, pls. 5-6, figs. 88-115 composed of* Stratigraphic formations of the producing zones of the Los Angeles Basin oil fields, by Stanley G. Wissler, pp. 209-234, figs. 88-94, pl. 5; Correlation of the oil fields of the Santa Maria district, by Stanley G. Wissler and Frank E. Dreyer, pp. 235-238, fig. 95; Correlation of oil field formations on east side San Joaquin Valley, by Glenn C. Ferguson, pp. 239-246, figs. 96A-98; Correlation of oil field formations on west side of San Joaquin Valley, by Paul P. Goudkoff, pp. 247-252, figs. 99A-101; Origin, migration and accumulation of oil in California, by Harold W. Hoots, pp. 253-276, pl. 6, figs. 102-115.

The following is included with bulletin, or may be obtained alone: Index map of the economic minerals in California (showing also geomorphic provinces) scale 1″ = 80 mi. Free.

(c) Part 3, Descriptions of individual oil and gas fields, pp. 277-664, 81 index maps, figs. 116, 282, containing Citations to selected references, by Elisabeth L. Egenhoff, pp. 278 et seq. throughout Part 3, Index maps 101-122, 201-217, 301-307, 401-432, 501-503. *Chapter 8, Los Angeles Basin and southernmost California, pp. 281-369, figs. 116-152 composed of* Los Angeles City oil field, by E. K. Soper, pp. 282-283, fig. 116; Salt Lake oil field, by E. K. Soper, pp. 284-286, fig. 117; Beverly Hills oil field, by E. K. Soper, p. 287, fig. 118; Whittier oil field, by W. H. Holman, pp. 288-291, figs. 119-121; Playa del Rey oil field, by Loyde H. Metzner, pp. 292-294, fig. 123; El Segundo oil field, by Richard G. Reese, pp. 295-296, fig. 124; Lawndale oil field, by Richard G. Reese, p. 297; Torrance oil field, by Eugene L. Davis, pp. 298-300, fig. 125; Wilmington oil field, by Read Winterburn, pp. 301-305, figs. 126-127; Inglewood oil field, by Herschel L. Driver, pp. 306-309, fig. 128; Potrero oil field, by Robin Willis and Richard S. Ballantyne Jr., pp. 310-317, figs. 129-131; Dominguez oil field, by S. Grinsfelder, pp. 318-319, fig. 132; Long Beach oil field, by Harry P. Stolz, pp. 320-324, figs. 133-134; Seal Beach oil field, by Glenn H. Bowes, pp. 325-328, figs. 135-137; Huntington Beach oil field, by D. K. Weaver and V. H. Wilhelm, pp. 329-331, fig. 138; Newport oil field, by Frank S. Parker, pp. 332-334, fig. 139; West Montebello area of the Montebello oil field, by Harry P. Stolz and A. F. Woodward, pp. 335-339, fig. 140; Montebello area of the Montebello oil field, by Richard G. Reese, pp. 340-342, fig. 141; Santa Fe Springs oil field, by H. E. Winter, pp. 343-346, fig. 142; West Coyote area of the Coyote Hills oil field, by Richard G. Reese, pp. 347-348; East Coyote area of the Coyote Hills oil field, by Paul H. Dudley, pp. 349-354, figs. 143-146; Yorba Linda area of the Coyote Hills oil field, by Frank S. Parker, pp. 355-356, fig. 147; Richfield area of the Richfield oil field, by Chester M. Gardiner, pp. 357-360, figs. 148-149; Kraemer area of the Richfield oil field, by Richard G. Reese, p. 361; Chino area, by Max L. Krueger, pp. 362-363, fig. 150; Cretaceous formations of the northern Santa Ana Mountains, by W. P. Popenoe, pp. 364-366, fig. 151; Southwestern San Diego County, by Leo George Hertlein and U. S. Grant IV, pp. 367-369, fig. 152. *Chapter 9, Ventura Basin and Transverse Ranges, pp. 370-424, figs. 153-176, composed of* Gaviota-Concepcion area, by William W. Porter II, pp. 372-373; Capitan oil field, by George R. Kribbs, pp. 374-376, figs. 153-154; Goleta oil field, by Frederick P. Vickery, pp. 377-379, fig. 155; Elwood oil field, by Mason L. Hill, pp. 380-383, figs. 156-157; La Goleta gas field, by R. O. Swayze, pp. 384-385, fig. 158; Summerland oil field, by Emil Kluth, p. 386; Rincon oil field, by R. E. Stewart, pp. 387-389, fig. 159; Ventura Avenue oil field, by C. C. Thoms and Wm. C. Bailey, pp. 391-393, fig. 160; Santa Paula oil field, by Louis N. Waterfall, p. 394, fig. 161; Sespe oil field, by Thomas Clements, pp. 395-399, fig. 162; Piru oil field, by H. D. Hobson, pp. 400-403, figs. 163-165; South Mountain oil field, by Loring B. Snedden, pp. 404-405, fig. 166; Bardsdale area of the Bardsdale oil field, by Loring B. Snedden, p. 406; Shiells Canyon area of the Bardsdale oil field, by Loring B. Snedden, p. 407; Del Valle oil field, by R. W. Sherman, pp. 408-411, figs. 167-169; Newhall oil field, by W. S. W. Kew, pp. 412-416, figs. 170-171; Simi oil field, by T. F. Stipp, pp. 417-423, figs. 172-176; Conejo oil field, by John C. May, p. 424. *Chapter 10, Santa Maria Basin and southern Coast Ranges, pp. 425-481, figs. 177-202 com-*

posed of Lompoc oil field, by T. W. Dibblee Jr., pp. 427-429, fig. 177; Casmalia oil field, by William W. Porter II, p. 430; Santa Maria (Orcutt) oil field, by F. E. Dreyer, p. 431; West Cat Canyon area of the Cat Canyon oil field, by Charles Manlove, pp. 432-434, fig. 178; East Cat Canyon area of the Cat Canyon oil field, by Rodman K. Cross, pp. 435-437, figs. 179-180; Gato Ridge area of the Cat Canyon oil field, by Rodman K. Cross, pp. 438-439, fig. 181; Santa Maria Valley oil field, by Charles R. Canfield, pp. 440-442, figs. 182-183; Geology of Huasna area, by N. L. Taliaferro, pp. 443-447, figs. 184-185; Huasna area development, by Vernon L. King, pp. 448-449; Arroyo Grande (Edna) oil field, by Max L. Krueger, pp. 450-452, fig. 186; Caliente Range, Cuyama Valley, and Carrizo Plain, by J. E. Eaton, pp. 453-455, figs. 187-188; Bradley-San Miguel district, by N. L. Taliaferro, pp. 456-462, fig. 189; Type locality of the Vaqueros formation, by Richard R. Thorup, pp. 463-466, figs. 190-192; Soledad quadrangle, by L. F. Schombel, pp. 467-470, figs. 193-195; Cantua-Vallecitos area, by E. R. Atwill, pp. 471-474, figs. 196-199; Sargent oil field, by James Michelin, pp. 475-476, fig. 200; Moody Gulch oil field, by Max L. Krueger, p. 477, fig. 201; Halfmoon Bay district, by Richard R. Crandall, pp. 478-480, fig. 202; Mount Diablo region, by Charles M. Cross, p. 481. *Chapter 11, San Joaquin Valley and bordering foothills, pp. 482-583, figs. 203-258, composed of* Geologic horizons of oil and gas fields of San Joaquin Valley and farther north, by Paul J. Howard, p. 483, fig. 203; Coalinga oil field, by Max Birkhauser, pp. 484-485, fig. 204; Coalinga East Extension area of the Coalinga oil field, by L. S. Chambers, pp. 486-490, figs. 205-207; Kettleman Hills oil fields, by John Galloway, pp. 491-493, fig. 208; Lost Hills oil field, by G. S. Follansbee Jr., pp. 494-495, figs. 209-210; Devils Den oil field, by Martin Van Couvering and H. B. Allen, pp. 496-501, figs. 211-213; Belridge oil field, by J. B. Wharton, pp. 502-504; Temblor oil field, by R. R. Simonson, pp. 505-506, fig. 214; McKittrick Front and Cymric areas of the McKittrick oil field, by E. R. Atwill, pp. 507-509, figs. 215-216; McKittrick area of the McKittrick oil field, by John B. Stevens, pp. 510-511, fig. 217; Elk Hills oil field (U. S. Naval Petroleum Reserve No. 1), by Lawrence E. Porter, pp. 512-516, figs. 218-220; Buena Vista Hills area of the Midway-Sunset oil field, by J. H. McMasters, pp. 517-518, fig. 221; North Midway area of the Midway Sunset oil field, by W. T. Woodward, pp. 519-521, figs. 222-223; Republic area of the Midway-Sunset oil field, by Umberto Young, pp. 522-525, fig. 224; Williams and Twenty-five Hill areas of the Midway-Sunset oil field, by Donuil Hillis and W. T. Woodward, pp. 526-529, figs. 225-228; Gibson area of the Midway-Sunset oil field, by W. T. Woodward, pp. 530-531, figs. 229-230; Wheeler Ridge oil field, by S. H. Gester, pp. 532-533, fig. 231; Type locality of the Tejon formation, by Jay Glenn Marks, pp. 534-538, figs. 232-233; Dudley Ridge gas field, by Gerard Henny, pp. 539-540, fig. 234; Semitropic gas field, by W. W. Valentine, p. 542, fig. 235; Buttonwillow gas field, by L. S. Chambers, pp. 543-545, figs. 236-237; Canal oil field, by R. N. Williams Jr., pp. 546-547, fig. 238; Strand oil field, by Charles M. Cross, p. 548, fig. 239; Ten Section oil field, by A. W. Gentry, pp. 549-550, fig. 240; Trico gas field, by E. C. Doell, pp. 551-552, figs. 241-242; Wasco oil field, by Roy M. Barnes, pp. 553-555, fig. 243; Rio Bravo oil field, by Earl B. Noble, pp. 556-558, fig. 244; Greeley oil field, by W. P. Winham, pp. 559-561, figs. 245-246; Fruitvale oil field, by Robert H. Miller and Glen W. Ledingham, pp. 562-564, fig. 247; Mountain View oil field, by Robert H. Miller and Glenn C. Ferguson, pp. 565-570, fig. 248; Kern Front area of the Kern River oil field, by Everett C. Edwards, pp. 571-574, figs. 249-252; Kern River area of the Kern River oil field, by John B. Stevens, p. 575, fig. 253; Edison oil field, by Everett C. Edwards, pp. 576-578, figs. 254-255; Round Mountain oil field, by R. G. Rogers, pp. 579-583, figs. 256-258; *Chapter 12, Northern San Joaquin Valley, Sacramento Valley, and northern Coast Ranges, pp. 584-635, figs. 259-282, composed of* Tracy gas field, by H. T. Beckwith, pp. 586-587, fig. 259; McDonald Island gas field, by George L. Knox, pp. 588-590, fig. 260; Rio Vista gas field, by E. K. Soper, pp. 591-594, fig. 261; Potrero Hills gas field, by Frank B. Tolman, pp. 595-598, figs. 262-263; Fairfield Knolls gas field, by J. M. Kirby, pp. 599-600, fig. 264; Rumsey Hills area, by J. M. Kirby, pp. 601-605, figs. 265-266; Sites region, by J. M. Kirby, pp. 606-608,

figs. 267-268; Willows gas field, by R. N. Williams Jr., p. 609, fig. 269; Marysville Buttes (Sutter Buttes) gas field, by Harry R. Johnson, pp. 610-615, figs. 270-271; Berryessa Valley, by F. M. Anderson, pp. 616-618, fig. 272; Paskenta region, by Robert L. Rist and William C. Harrington, pp. 619-620, figs. 273-274; Duxbury Point region, by James M. Douglas, p. 621, fig. 275; Petaluma region, by F. A. Johnson, pp. 622-627, figs. 276-279; Point Arena-Fort Ross region, by Charles E. Weaver, pp. 628-632, fig. 280; Central and southern Humboldt County, by Harry D. MacGinitie, pp. 633-635, figs. 281-282. *Chapter 13, Tabulated data on wells drilled outside of the principal oil and gas fields, pp. 636-664.*

Part 4, Glossaries, bibliography, and index, pp. 665-773, figs. 283-284, containing the following chapters: Chapter 14, Glossary of the geologic units of California, compilation based largely on the work of M. Grace Wilmarth and Alice S. Allen, abstracted and revised by Olaf P. Jenkins, pp. 666-687, figs. 283-284. Chapter 15, Bibliography, pp. 688-720, with list of publications cited throughout Bulletin 118, by Elisabeth L. Egenhoff, pp. 689-720. Chapter 16, Index to Bulletin 118, by Elisabeth L. Egenhoff, pp. 722-773.

The following is included with report, or may be purchased alone: Outline geologic map of California showing oil and gas fields and drilled areas (Economic mineral map of California no. 2—Oil and gas), scale 1:1,000,000, by Olaf P. Jenkins. 1941. Price $1.00.

119. California mineral production and directory of mineral producers for 1939, by Henry H. Symons. 1941. 223 pp., 8 illus. Free.

*120. Manner of locating and holding mineral claims in California, by A. H. Ricketts (with revisions by C. McK Laizure, August 1941). 1941. 26 pp.

121. California mineral production and directory of mineral producers for 1940, by Henry H. Symons. 1941. 227 pp., 12 illus. Free.

122. California mineral production and directory of mineral producers for 1941, by Henry H. Symons. 1942. 377 pp., 8 figs. Free.

*123. American mining law, with forms and precedents, by A. H. Ricketts. 1943. 1018, xvi pp.

*124. Commercial minerals of California, by George L. Gary. 1942. 166 pp., mimeographed.

125. Manganese in California, prepared under the direction of Olaf P. Jenkins. 1943. 387 pp., 1 map, 46 figs. Cloth-bound, price $3.00.

Contains: Preface, by Olaf P. Jenkins, pp. 9-12; History of the manganese industry, by Robert Scott Kroger, pp. 13-21; Occurrence and minerals of manganese, by Theo H. Crook, pp. 23-40; Utilization of California manganese ores, by O. Cutler Shepard, pp. 41-49, 2 figs.; Manganese deposits of California, a summary report, by Parker D. Trask, Ivan F. Wilson, and Frank S. Simons, pp. 51-215, 2 figs.; Genesis of the manganese deposits of the Coast Ranges of California, by N. L. Taliaferro and F. S. Hudson, pp. 217-275, 22 figs.; Manganese deposits of the Sierra Nevada, their genesis and metamorphism, by N. L. Taliaferro, pp. 277-332, 20 figs.

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126. California mineral production and directory of mineral producers for 1942, by Henry H. Symons, 1943. 224 pp., 7 illus. Free.

*127. Manner of locating and holding mineral claims in California, by A. H. Ricketts (with revisions by C. A. Logan, March 1944). 1944. 35 pp.

128. California mineral production and directory of mineral producers for 1943, by Henry H. Symons. 1944. 222 pp., 10 illus. Free.

129. Iron resources of California, prepared under the direction of Olaf P. Jenkins. 1948. 304 pp., 25 pls., 68 figs. Price $2.50.

Contains: Preface, by Olaf P. Jenkins, pp. ix-xii; Parts A-P, see below; Bibliography of the iron-ore resources of California, by Elisabeth L. Egenhoff, pp. 269-300; Index, pp. 302-304.

Issued also in separate parts, as indicated below.

(a) Iron-ore deposits in the eastern part of the Eagle Mountains, Riverside County, California, by Jarvis B. Hadley, pp. 1-24, pls. 1-3, figs. 1-11. Free.

(b) Iron Mountain iron-ore deposits, Lava Bed district, San Bernardino County, California, by Carl A. Lamey, pp. 25-38, pl. 4, figs. 12-15. Free.

(c) Iron Mountain and Iron King iron-ore deposits, Silver Lake district, San Bernardino County, California, by Carl A. Lamey, pp. 39-58, pls. 5-7, figs. 16-19. Free.

(d) Old Dad Mountain iron-ore deposit, San Bernardino County, California, by Carl A. Lamey, pp. 59-68, figs. 20-22. Free.

(e) Cave Canyon iron-ore deposits, San Bernardino County, California, by Carl A. Lamey, pp. 69-84, pl. 8, figs. 23-29. Free.

(f) Vulcan iron-ore deposit, San Bernardino County, California, by Carl A. Lamey, pp. 85-96, pl. 9, figs. 30-33. Free.

(g) Iron Hat (Ironclad) iron-ore deposits, San Bernardino County, California, by Carl A. Lamey, pp. 97-109, pl. 10, figs. 34-37. Free.

(h) Ship Mountains iron-ore deposit, San Bernardino County, California, by Carl A. Lamey, pp. 110-116, pls. 11-12, fig. 38. Free.

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*(l) Iron-ore deposits near Lake Hawley and Spencer Lakes, Sierra County, California, by Cordell Durrell and Paul D. Proctor, pp. 165-192, pls. 20-23, figs. 54-57.

*(m) Iron deposits of the Kingston Range, San Bernardino County, California, by D. F. Hewett, pp. 193-206, pl. 24, fig. 58.

*(n) Summary of the iron-ore situation in California, by Ernest F. Burchard, pp. 207-230, figs. 59-64.

*(o) Summary of investigations of iron-ore deposits of California, by A. C. Johnson and Spangler Ricker, pp. 231-242.

*(p) Titaniferous iron-ore deposits of the western San Gabriel Mountains, Los Angeles County, California, by Gordon B. Oakeshott, pp. 243-266, pl. 25, figs. 65-68.

130. Economic mineral resources and production of California; A survey with reference to postwar employment, by Samuel H. Dolbear. 1945. 219 pp., pp. A1-56, B1-146, C1-23, Index pp. 1-14, 3 maps. Price, $2.00.

Contains: Preface, by Samuel H. Dolbear, pp. 7-8; Summary, pp. 9-10; Place and function of minerals in the state's economy, pp. 11-25; California mineral reserves, pp. 26-30, 1 map; Employment in California mineral industries, by S. R. Coghlan, pp. 31-41; Legislative and other control in mineral industry, pp. 42-43; Needed changes in California statutory and administrative law, by Robert M. Searls, pp. 44-46; Needed changes in federal statutory and administrative law, by Philip R. Bradley Jr., pp. 47-54; Possible expansion of California mineral industries, pp. 55-59; The chemical industry as consumer of California minerals, by Herbert Waterman, pp. 60-70; Postwar construction and new equipment projects, pp. 70-71; National mineral policy, pp. 72-73. Commercial minerals of California, pp. 74-219, includes: Aluminum, pp. 75-76; Antimony, p. 76; Asbestos, pp. 77-78; Barite, pp. 78-80; Bentonite and fullers earth, pp. 80-82; Bituminous rock, pp. 82-83; Borates, pp. 83-86; Bromine, pp. 86-87; Building stone, pp. 87-89; Calcium chloride, p. 90; Calcium silicate, p. 90; Carbon dioxide gas, p. 91; Cement, pp. 92-97; Chromite, pp. 97-100; Clay

and clay products, by J. Clark Sutherland, pp. 100-106; Coal, p. 107; Copper, lead, and zinc, by Hadley R. Bramel, pp. 107-118; Diatomite, pp. 118-120; Feldspar, pp. 120-121; Garnet (abrasive), pp. 121-122; Gold, by G. A. Joslin, pp. 122-151; Gypsum, pp. 151-155; Iodine, p. 155; Iron and steel, by H. Foster Bain, pp. 155-165; Lime, limestone, and dolomite, by Roy E. Tremoureux, pp. 165-169; Lithium, pp. 169-171; Magnesite and magnesium compounds, by S. R. Coghlan, pp. 171-174; Magnesium, pp. 175-176; Manganese, pp. 176-179; Mineral water, p. 180; Minor minerals, pp. 181-182; Molybdenum, pp. 182-183; Platinum, p. 184; Potash, pp. 184-186; Pumice, pp. 187-189; Pyrites, pp. 189-190; Quicksilver, pp. 191-196; Salt, by Walter W. Bradley, pp. 196-199; Semi-precious stones and crystals, p. 199; Silica, pp. 199-201; Sillimanite group, pp. 202-204; Soda ash-salt cake, pp. 204-207; Stone, miscellaneous, pp. 207-210; Strontium, p. 210; Sulphur, pp. 210-211; Talc and steatite, by J. Clark Sutherland, pp. 211-215; Tungsten, pp. 215-219. Appendix A: Directory of producers, pp. A1-56; Appendix B: Mineral production by counties, pp. B1-146; Appendix C, pp. C1-23 includes Public Resources Code, pp. C1-4; and Publications of the Division of Mines, pp. C5-23. Index, pp. 1-14.

The following are included with bulletin, or may be obtained alone: Map of California showing progress in topographic quadrangles and geologic maps, scale 1″ = 40 mi. (approx.); and Map of California showing distribution of mineral deposits, scale 1″ = 40 mi. (approx.); prepared by Olaf P. Jenkins; free. Commercial minerals of California (chart), free.

131. Consolidated index of publications, Division of Mines and State Mining Bureau, 1880-1943, by Walter W. Bradley, 1945. 872 pp., i-xxi. Price $8.75.

132. California mineral production and directory of mineral producers for 1944, by Henry H. Symons. 1945. 224 pp., 6 illus. Free.

133. Geology of the San Juan Bautista quadrangle, California. 1946. 112 pp., 12 pls., 1 index map, 10 figs. Price $1.50.

Contains: Map of California, index to quadrangles published by Division of Mines, op. p. 7; Preface, by Olaf P. Jenkins, pp. 7-8; Geology of the San Juan Bautista quadrangle, California, by John Eliot Allen, pp. 9-75, pls. 1-8, figs. 1-10; Operations of the Granite Rock Company quarry and plant at Logan, San Benito County, by Royal E. Fowle, pp. 77-81, pls. 9-12.

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134. Geological investigations of chromite in California, prepared under the direction of Olaf P. Jenkins.

Issued in separate parts and chapters, as indicated below.

(a) Part I, Klamath Mountains.

Chapter 1, Chromite deposits of Del Norte County, California, by Francis G. Wells, Fred W. Cater, Jr. and Garn A. Rynearson, pp. 1-76, pls. 1-11, 9 figs., 1946. Price 75¢.

The following is included with the report or may be purchased alone: Topographic map of Del Norte County, California, showing distribution of peridotite and location of chromite deposits, scale 1″ = 2 mi. Price 40¢.

(b) Part II, Coast Ranges.

Chapter 1, Chromite deposits of the northern Coast Ranges of California, by D. H. Dow and T. P. Thayer, pp. 1-38, 2 figs., 1946. Price 25¢.

(c) Part III, Sierra Nevada.

Chapter 1, Chromite deposits of Tuolumne and Mariposa Counties, California, by Fred W. Cater, Jr. pp. 1-32, pls. 1-4, 2 figs., 1948. Price 35¢.

Chapter 2, Chromite deposits of Calaveras and Amador Counties, California, by Fred W. Cater, Jr. pp. 33-60, pl. 5, fig. 1, 1948. Price 35¢.

Chapter 3, Chromite deposits of Tulare and eastern Fresno Counties, California, by Garn A. Rynearson, pp. 61-104, pls. 6-7, 7 figs., 1948. Price 50¢.

135. Placer mining for gold in California, by Charles Volney Averill. 1947. 377 pp., 4 pls., 106 figs. Cloth-bound, price $2.50.

Contains: *Placer mining methods, pp. 11-146, pl. 1, figs. 1-45, which includes* Small-scale methods, pp. 13-33, figs. 1-9; Dragline dredging, pp. 34-48, pl. 1, figs. 10-18; Dryland dredges, pp. 49-50, fig. 19; Bucket-line dredging, by Charles M. Romanowitz and Herbert A. Sawin, pp. 51-60, figs. 20-22; Becker-Hopkins single-bucket dredge, by H. A. Sawin, pp. 61-62, figs. 23-24; Jigging applied to gold dredging, by P. Malozemoff, pp. 63-72, fig. 25; Notes on jigs for gold dredges, by F. W. Collins, pp. 73-76, figs. 26-29; Treatment of black sand, pp. 77-80, fig. 30; Drift mining, general description, pp. 81-88, fig. 31; A synoptic presumption regarding California's drift mines, by L. L. Huelsdonk, pp. 89-91; Hydraulic mining, pp. 93-143, figs. 32-45; Debris dams, pp. 144-146. *Geology of placer deposits, pp. 146-216, figs. 46-80, which includes* New technique applicable to the study of placers, by Olaf P. Jenkins, pp. 149-216, figs. 46-80. *Prospecting and sampling placer deposits, pp. 217-227, which includes* Sampling, pp. 219-226; Geophysical prospecting, p. 227. *Placer mines by counties, pp. 229-322, figs. 81-106, which includes* Amador, Butte, Calaveras, El Dorado, Fresno, Humboldt, Imperial, Kern, Los Angeles, Madera, Mariposa, Merced, Nevada, Placer, Plumas, Sacramento, San Bernardino, San Joaquin, Shasta, Sierra, Siskiyou, Stanislaus, Trinity, Tuolumne, Yuba Counties, pp. 231-315, figs. 81-104; Deep gravels dredged successfully, by Herbert A. Sawin, pp. 317-322, figs. 105-106. *Appendix—laws affecting placer mining, pp. 323-336, which includes* The Caminetti Law, pp. 325-330; Amendments to the Caminetti Act, pp. 331-333; Definition of hydraulic mining, p. 333; Definition of hydraulic mining from California Civil Code, p. 333; Trinity and Klamath River fish and game district, p. 334; Protection of domestic water supplies, pp. 335-336; Placer mining districts, p. 336; Map showing Tertiary gravel channels, Nevada County, California, scale 2″ = 3 mi. (approx.), pl. 2, in pocket.

The following are included with bulletin, or may be purchased separately: Geologic map of northern Sierra Nevada showing Tertiary river channels and Mother Lode belt, prepared by Olaf P. Jenkins, scale 1″ = 8 mi., pl. 3, (*Report accompanying geologic map of northern Sierra Nevada,* by Olaf P. Jenkins, printed on back), price 25¢. Map of northern California showing placer mining areas, scale 1″ = 18 mi., pl. 4, price 25¢.

136. Minerals of California, by Joseph Murdoch and Robert W. Webb. 1948. 402 pp., 4 pls., 1 fig. Price $3.00.

137. California mineral production and directory of mineral producers for 1945, by Henry H. Symons. 1946. 221 pp. Free.

*138. Manner of locating and holding mineral claims in California, by A. H. Ricketts (with revisions by C. A. Logan). 1946. 35 pp.

139. California mineral production for 1946, by C. V. Averill, C. R. King, Henry H. Symons, and F. F. Davis. 1948. 176 pp., 4 pls. Price 75¢.

Contains: Summary of the mineral industry in California during the year 1946, pp. 9-10; Fuels, pp. 11-27; Metals, pp. 29-56; Industrial nonmetallic materials, pp. 57-102; Salines, pp. 103-112. Appendix, pp. 113-172: List of counties in California, showing amount and value of the mineral substances produced in each during 1946, pp. 115-127; Directory of producers of metallic and nonmetallic minerals in California in 1946, pp. 129-167; List of smelters reporting purchase of California metals produced in 1946, p. 168; List of custom mills and commercial grinding plants in California, p. 169; List of quicksilver buyers and mineral brokers, p. 170; List of commercial assay and testing laboratories, p. 171.

FINDING LIST OF AUTHORS

Abbreviations used: M, maps; SP, special publications; PR, preliminary reports; RM, register of mines; R, reports of the State Mineralogist; J, California Journal of Mines and Geology; B, bulletins.

NOTE: PLEASE DO NOT ORDER FROM FINDING LIST; REFER TO TEXT TO SEE WHETHER PUBLICATION IS STILL IN STOCK. PUBLICATIONS MARKED WITH AN ASTERISK (*) ARE OUT OF PRINT AND CANNOT BE PURCHASED FROM THE DIVISION OF MINES.

FINDING LIST OF SUBJECTS

Abbreviations used: M, maps; SP, special publications; PR, preliminary reports; RM, register of mines; R, reports of the State Mineralogist; J, California Journal of Mines and Geology; B, bulletins.

NOTE: PLEASE DO NOT ORDER FROM FINDING LIST; REFER TO TEXT TO SEE WHETHER PUBLICATION IS STILL IN STOCK. PUBLICATIONS MARKED WITH AN ASTERISK (*) ARE OUT OF PRINT AND CANNOT BE PURCHASED FROM THE DIVISION OF MINES.

15—92259

LIST OF DEPOSITORY LIBRARIES SHOWING THEIR HOLDINGS OF DIVISION OF MINES PUBLICATIONS

Introduction*

For many years the Division of Mines has been sending its publications to an ever-increasing number of libraries. This process is in keeping with the California statute of 1939 which states that "He [the State Mineralogist] may also furnish the publications of the Division to public libraries without cost and may exchange publications with geological surveys, scientific societies, and other like bodies."

Present depository libraries fall into four overlapping groups: public, exchanging society or institution, government, and school libraries. Most of these libraries are located in California, but there are many in other states and foreign countries.

In an effort to inform the public where Division of Mines publications are available for study, the Division circularized 245 libraries on its mailing list (including a few formerly on the Division mailing list which are now receiving Division of Mines publications through the State Supervisor of Publications Distribution) early in March 1948, requesting of each library information on completeness of its collection of Division of Mines publications. There were some libraries which, although presently on the Division mailing list, were not circularized because there was some question as to the availability of the publications on their shelves to the general public. It is believed that the libraries in the following list are open to the general public, although borrowing privileges may be limited. Public libraries which may have been missed in the current circularization are invited to submit reports for a future edition of this list.

Division of Mines district offices are located in Redding, Sacramento, and Los Angeles. Each office has available for reference a nearly complete collection of Division publications.

If any publication of interest is not in a local library, application to borrow it on interlibrary loan may be made to the California State Library in Sacramento.

The Division librarian is grateful for the cooperation shown by many in making publication of this specialized directory possible. Pleased to encourage study of its publications, the Division offers complimentary copies of in-print items to public libraries upon request.

Libraries listed below for which no holdings are shown, are on the Division of Mines mailing lists, and receive current publications; however, no itemized statements of their holdings are available at present.

The list of libraries has been arranged as follows: (1) California libraries, arranged alphabetically by town and name of library; (2) Libraries in states other than California, arranged alphabetically by state, city, and name of library; (3) Libraries in foreign countries, arranged alphabetically by country and city.

Abbreviations used: M, maps; SP, special publications; PR, preliminary reports; RM, register of mines; R, reports of the State Min-

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* Prepared by Roy Nielsen, Librarian, California State Division of Mines, April 28, 1948.

eralogist; J, California Journal of Mines and Geology; B, bulletins. A plus sign following the last number in a series (B 10, 112, 113, 115+) indicates that the library has all subsequent issues in the series.

California

Alameda, Alameda County
Alameda Free Library
M 16, 18, 19; RM 19-20; R 1-14, 17, 18d,g,h,i,j,l, 19b,c,d, 20a,b,d, 21a, 22c, 23a,b,d, 24a,d, 25c,d, 26a,d, 27a,b,d, 28a,c, 29b, 30, 31a,b,d, 32-33, 34b,c,d, 35-42; J 43+; B 2-6, 9-11, 23, 30, 38, 45-46, 50, 57, 74, 76-79, 83, 86, 88-91, 94, 98-99, 101, 104, 106-107, 109-119, 121-122, 125+

Alhambra, Los Angeles County
Alhambra Public Library, 410 West Main St.
R 18e,f, 19d, 20a,b,d, 21b, 22a,c,d, 23a,c,d, 25a,c, 26a,b,d, 27a,d, 34b,c,d, 35, 36a,b,d, 37b,c,d, 38a,c, 39a,b,d, 40a,b,c; J 43+; B 96, 103, 105, 107, 113

Anaheim, Orange County
Anaheim Public Library, 241 South Los Angeles St.

Arcata, Humboldt County
Humboldt State College Library
RM 7; R 29a, 32a,b, 34c,d, 35b,c,d, 36-42; J 43+; B 137

Auburn, Placer County
Auburn City Library, 175 Almond St.
Placer County Free Library

Bakersfield, Kern County
Kern County Free Library
R 2, 6-13, 15-42; J 43+; B 3-7, 9-11, 16, 23, 27, 32, 37, 50, 57, 63, 65-66, 68-76, 78-79, 83-84, 86-114, 116-137

Balboa, Orange County
Newport Beach Public Library, 106 Island Ave.

Beaumont, Riverside County
Beaumont District Library
R 23a,d, 24a,b,c, 25c,d, 26a,b,c, 27-28, 31d, 34-42; J 43+; B 106, 131, 137, 139+

Berkeley, Alameda County
Berkeley Public Library, Shattuck and Kittredge
M 18; RM 1-4; R 2-12, 14-23, 24b,c,d, 25-42, J 43+; B 6, 23, 32, 37-38, 46-47, 49-56, 58-59, 62-74, 76-79, 83-122, 124-127, 131+
University of California Library, Documents Dept.
Complete.

Blythe, Riverside County
Blythe Public Library

Carmel, Monterey County
Carmel Public Library, Box 800

Chico, Butte County
Chico Public Library
Chico State College Library
R 16a, 23d, 24b, 25c,d, 38-42; J 43+; B 38, 104, 108, 113, 115, 133, 137

Chula Vista, San Diego County
Chula Vista Public Library
R 33, 34b,d, 35c,d, 36-42; J 43+; B 1-3, 5, 7, 9-10, 17-18, 20, 26-27, 30-32, 36, 38-39

Claremont, Los Angeles County
Claremont College Library
R 1-2, 5-42; J 43+; B 4, 6, 19, 23, 37-38, 46, 50, 54-74, 76-88, 91+
Pomona College Library
R 3-4, 6-13, 17, 18-42; J 43+; B 1-6, 9-11, 16, 18-19, 23-24, 27, 30-37, 53, 63, 68-69, 72, 74-78, 83, 89, 91, 95, 104 115 118, 121, 131, 135-137

Coalinga, Fresno County
Coalinga District Library
M 18; R 6, 18h, 20b,d, 22c, 25c, 27b, 34a, 35c, 37-40, 41b,c,d, 42a,c,d; J 43+; B 6, 27, 32, 37, 63, 69, 82, 84, 104, 115, 118, 120, 122-124, 130-131, 137

Colusa, Colusa County
Colusa County Free Library, Hall of Records Bldg.

Crescent City, Del Norte County
Del Norte County Library

El Centro, Imperial County
El Centro Public Library
Imperial County Free Library

Escondido, San Diego County
Escondido Public Library, 255 South Kalmia St.
R 14, 21c,d, 22, 23a,b,c, 25, 26b,c,d, 27a,b, 28a,c, 29, 30c, 31b,c, 33b; P 43+; B 72, 79 92

Eureka, Humboldt County
Eureka Free Library, 7th and F Sts.
R 16a, 18d,f,h, 19a,b, 20a,c, 21, 23a,b, 24-25, 26a,c,d, 27b,d, 28a, 31b,d, 32, 33b,c, 34a,d, 35a,b,c, 36a,c, 37d, 38-42; J 43+; B 45, 66, 70-74, 77, 79, 83, 85-86, 88, 90-92, 98-99, 104, 106, 108, 111-112, 114-119, 122-123, 125-126, 128+

Fairfield, Solano County
Solano County Free Library

Fresno, Fresno County
Fresno County Free Library, 1330 Broadway
M 16; RM 11; R 5-11, 14-42; J 43+; B 2, 6, 19, 23-24, 27, 30, 37-38, 47, 50-52, 54-59, 61-71, 73-79, 83-97, 99+
Fresno State College Library
R 11, 18c,d,g,h,i,j,l, 19, 20a,b,d, 21a,b,c, 22-24, 25b,c,d, 26-29, 30a,b, 31a,c,d, 32-33, 34b,c,d, 35-37, 39a,b,d, 40, 41a,c,d, 42; J 43+; B 23, 50, 70-71, 74, 79, 83, 86-88, 90-91, 93-103, 107, 109-112, 114, 116-118, 121-123, 125-126, 128+

Fullerton, Orange County
Fullerton Public Library, 301 North Pomona Ave.
R 18-28, 29b, 30a,c, 31a,b,d, 32-42; J 43+; B 27, 36-37, 50, 57, 63, 72, 75, 76, 79, 83-88, 90-94, 97-99, 101-102, 104-119, 121-137

Glendale, Los Angeles County
Glendale Public Library, 319 E. Harvard St.
R 22-32, 35, 37-40, 42; J 43+; B 50, 64-65, 74, 76-77, 79, 83, 86, 88, 90, 93, 97, 99, 101-103, 106-112, 135

Grass Valley, Nevada County
Grass Valley Free Public Library
R 8, 13-14, 16a,c, 18d,g,h,j,l, 19, 25c, 27a,b,d, 28c, 29, 30a,c, 31a,b,d, 32b,c,d, 33a, 35a,d, 37b,c,d, 38-42; J 43+; B 23, 50, 71, 83, 86, 88, 90, 92-94, 98, 102-105, 107-111, 117-119, 121-126, 128+

Hanford, Kings County
Kings County Free Library

Hemet, Riverside County
Hemet Public Library, 510 E. Florida Ave.
R 22a, 28a,c, 30c, 31a, 32-33, 34a,b,c, 35-41, 42a,b; J 43+; B 85, 137

Hollister, San Benito County
San Benito County Free Library
M 18; R 26a, 29b, 30b,c, 31a,c,d, 32, 33a,b,d, 34-35, 36a,b,c, 37-42; J 43+; B 46, 72, 74, 76-83, 86, 89, 91, 99, 104, 106, 113-116, 120, 131, 135

Independence, Inyo County
Inyo County Free Library
M 18; R 16b,c, 28b, 29a, 30, 31d, 32b,c,d, 34d, 35-42; J 43+; B 6, 50, 57, 63-65, 68-71, 73-79, 83, 85-86, 88-91, 94, 96-97, 99-108, 110-111, 113-115, 118-119, 121-123, 125-126, 128+

Jackson, Amador County
Amador County Library
RM 12; R 10, 12-14, 16, 29-30, 32-42; J 43+; B 76, 79, 88, 93-94, 96-97, 100-103, 105, 107-111, 113-114, 116-117, 119, 121-122, 124, 126, 131+

Lakeport, Lake County
Lakeport Carnegie Library
R 8, 10, 24b, 25d, 26a, 27c,d, 28a,c, 29a, 30c, 31d, 32b,d, 34c,d, 35b, 36a,d, 37d, 38a,c, 39-42; J 43+; B 105, 131, 135-137

Lodi, San Joaquin County
Lodi Public Library, 305 West Pine St.
M 18; R 34-42; 43+ B 135-137

Long Beach, Los Angeles County
Long Beach Public Library, Document Division
M 16, 18, 19; R 1-42; J 43+; B 3, 6, 11, 16, 19, 23, 27, 30, 32, 36, 38, 46, 50, 57, 63-65, 67-72, 74-79, 83, 85-94, 96+

Los Angeles, Los Angeles County
California State Division of Mines, State Building, 217 West First St.
M 16, 18, 19; RM 1-21; R 1-42; J 43+; B 1-13, 15-16, 18-19, 21-32, 34+
Los Angeles County Library, 322 South Broadway
Los Angeles County Museum Library, Exposition Park
R 6-8, 13, 19b,c, 28-42; J 43+; B 3, 6, 20, 32, 37, 50, 56, 62-63, 65-66, 68-71, 90-91, 104, 107-117, 119, 121-123, 125-126, 130-131, 135-37
Los Angeles Public Library
Arroyo Seco Branch, 6145 North Figueroa St.
Cahuenga Branch, 4591 Santa Monica Blvd.
Junipero Serra Branch, 4255 South Olive St.
B 91, 113, 138+
Serials Division, 630 West 5th St.
M 18, 19, RM 1-21; R 2, 5-17, 18a,b,c,d, 19-42; J 43+; B 1+
Vermont Square Branch, 1201 West 48th St.
Vernon Branch, 4504 Central Ave.
Occidental College Library
R 17, 18a,c,d,e,f,g,h,i,j,k,l, 19b,c,d, 20, 21a,b, 22-26, 27c, 28b,c, 29-30, 31d, 32d, 33, 34a,b,d, 35-42; J 43+; B 69, 74, 78-85, 87-91, 93-94, 96-107, 112-118, 122-123, 125-130, 132-133, 137+
University of California at Los Angeles, Geology Dept. Library, 405 Hilgard Ave.
University of Southern California Library, University Park

Madera, Madera County
Madera County Free Library
R 8, 14, 17-18, 19a, 20d, 21b, 22a, 23, 24a,c,d, 25a,b, 26a,b,c, 27-28, 29b, 30a,b, 31a,c,d, 32, 33a,b,c, 34-35, 36b,c,d, 37-42; J 43+; B 63, 66-67, 69-72, 76, 78, 84-85, 89, 98, 104, 106, 108, 115, 118, 123-125, 127, 130-135, 138+

Martinez, Contra Costa County
Contra Costa County Library, Hall of Records, Rm. 119
M 19; R 24, 25a,b,c, 26-27, 28a,c, 29-42; J 43+; B 72, 76, 85, 103-110, 112-114, 116-117, 119, 121, 124, 126-128, 131+

Marysville, Yuba County
Marysville City Library, 301 4th St., Box 991
R 11-13, 16-42; J 43+; B 2, 6, 9-10, 19, 23, 27, 36-38, 50, 56-57, 60, 63-74, 76-88, 90-91, 93-96, 98-119, 121-137

Merced, Merced County
Merced County Free Library, 2125 M St.
R 16, 18i, 19d, 20-28, 29a, 30-31, 32a,c,d, 33, 34a,c,d, 35-36, 37b,c,d, 38-42; J 43+; B 56-57, 60, 63-66, 68-75, 78-88, 90, 93-94, 96-97, 99-107, 109, 112, 114, 117-119, 121-137

Mills College, Alameda County
Mills College Library

Modesto, Stanislaus County
McHenry Public Library
Stanislaus County Free Library
R 14b, 15a, 16, 18-42; J 43+; B 65-68, 70-71, 73-74, 76-79, 83, 85-87, 90-91, 93-94, 96-105, 107-122, 125-126, 128, 131+

Mojave, Kern County
Kern County Free Library, Mojave Branch

Monterey, Monterey County
Monterey Public Library

Nevada City, Nevada County
Nevada City Free Library

North Hollywood, Los Angeles County
Los Angeles Public Library, Sidney Lanier Branch, 5211 Tujunga Ave.
R 39c,d, 40-41, 42a,b,c; J 43+; B 106, 108, 113, 124, 127, 135+

Oakland, Alameda County
Oakland Public Library, 14th and Grove Sts.
M 16, 18, 19; RM 8, 14. 17, 20-21; R 1-42; J 43+; B 3-4, 6-7, 16, 18-19, 27, 32, 36-37, 46, 49-50, 53, 56-57, 59, 61-84, 86-88, 90+

Orange, Orange County
Orange Public Library
R 31a,d, 37d, 38-42; J 43+; B 99, 122, 130-131, 135-137

Oroville, Butte County
Butte County Free Library
RM 17; R 15b, 16a, 20d, 23-26, 27a,b,c, 28-29, 30a,b, 31, 32b,c,d, 33-35, 36a,b,d, 37-38, 39a,b,c, 40-42; J 43+; B 65, 67-68, 70-71, 74, 76, 78, 83, 85-88, 90-93, 97, 99, 103, 108-111, 113-114, 116-117, 119, 121-123, 126, 130, 132-135
Oroville Public Library
R 15, 16b, 18c,d,e,f,g,h,j,k,l, 19-21, 22a,b,d, 23, 24a,b,d, 25, 26d, 31d, 32-34, 35a,c,d, 36-40, 41b,c,d, 42; J 43+; B 36, 57, 76, 79, 93-94, 96-97, 100-102, 121, 137

Palo Alto, Santa Clara County
Palo Alto Public Library
R 2, 8-9, 11-13, 16-42; J 43+; B 50, 64-65, 67-68, 77-79, 90, 93-94, 98-99, 101-119, 121-123, 125-126, 128-137

Pasadena, Los Angeles County
California Institute of Technology Library
M 16; RM 3, 5-7, 10, 12, 16, 18-20; R 2, 4-14, 16-19, 20a,b,d, 21-42; J 43+; B 2-4, 6, 9-12, 16, 18-19, 23-25, 27-28, 30-35, 39-40, 42-44, 46-47, 49-53, 57-60, 65-66, 68-74, 76-84, 86, 88-94, 97-110, 112-119, 121+
Pasadena Public Library, 285 East Walnut Ave.
M 16, 18; R 6b, 8, 10-14, 17, 18-42; J 43+; B 3, 5-6, 16, 23, 27, 30, 38, 50, 53, 56-57, 70-79, 83-88, 90-105, 107, 109-126, 128+

Paso Robles, San Luis Obispo County
Paso Robles Public Library

Petaluma, Sonoma County
Petaluma Public Library
R 11, 34b,c,d, 35a,d, 36, 37d, 38-41, 42a,b,d; J 43+; B 76, 78-79, 91, 95, 108, 113, 135-137

Placerville, El Dorado County
El Dorado County Free Library (formerly Placerville Public Library)
R 10, 22d, 26c, 27a,b,d, 28, 31c,d, 32a, 33a,d, 34d, 35b,c,d, 36, 37d, 38-41, 42a,b,c; J 43+; B 76, 83, 86, 88, 90-91, 93, 99, 102-107, 111, 116-118, 122-123, 125+

Pomona, Los Angeles County
Mt. San Antonio College Library, Box 801
Pomona Public Library, 380 North Main St.
R 1-3, 5-15, 17, 29-42; J 43+; B 1-6, 9-10, 15, 18-19, 23-24, 27, 30-32, 35-36, 45+

Quincy, Plumas County
Plumas County Free Library

Randsburg, Kern County
Kern County Free Library, Randsburg Branch

Red Bluff, Tehama County
Tehama County Free Library
R 16, 21-25, 26a,b,c, 27-28, J 43+; B 23, 50, 76, 78-79, 86, 91-92, 99, 101-107, 109, 112, 119, 121, 125-126, 128-132, 135

Redding, Shasta County
California State Division of Mines, Redding district office
M 16, 18, 19; RM 13; R 6-42; J 43+; B 1-2, 4-7, 9-13, 15-16, 19-23, 25-32, 34, 36-61, 63-65, 67-79+
Redding Public Library

Redlands, San Bernardino County
University of Redlands Library
R 9-15, 18d,e,g,h,i,j,k,l, 19a,b,c, 20, 21b,c,d, 22, 23b,c,d, 24a,b,d, 25-35, 37-38, 40-41, 42b,c,d; J 43+; B 9, 23, 50, 63, 67, 74, 76-79, 83, 86, 88-90, 92-95, 98-99, 101, 103-104, 107-112, 114-117, 119-120, 122-128, 132, 137

Richmond, Contra Costa County
  Richmond Public Library
    R 18a,b,c,e,f,g,h,i,j,k,l, 19-21, 22b,c,d, 23-25, 26a,c,d, 27, 28b,c, 29, 30, 31b,c,d, 32b,c,d, 33-42; J 43+; B 37-38, 46, 63, 69, 71-72, 74, 76-77, 83, 86-88, 90, 108, 123, 131+

Riverside, Riverside County
  Riverside Public Library
    M 16, 18, 19; RM 4, 7, 12-14, 17, 20-21; R 1-5, 6b, 7-21, 23-42; J 43+; B 2-11, 16, 19-33, 36-38, 44-47, 49-60, 62-119, 121+

Roseville, Placer County
  Roseville Public Library, 557 Lincoln St.
    B 108, 123, 135

Sacramento, Sacramento County
  California State Division of Mines, Sacramento District Office
    M 16, 18, 19; RM 1-21; R 1-42; J 43+; B 1-2, 4-7, 9-13, 15-16, 18-19, 21-23, 25-34, 36-65, 67-83, 85+
  California State Library
    Complete file
  Sacramento City Library, Reference Dept.
    M 18, RM 1-2, 4-11, 14-16, 21; R 1-42; J 43+; B 1-60, 62-72, 74, 76-79, 83, 85-91, 93-105, 107-108, 110-114, 116-126, 128+

Salinas, Monterey County
  Salinas Public Library
    R 20a, 36-42; J 43+; B 113, 118, 121, 123, 127, 131, 135-137

San Andreas, Calaveras County
  Calaveras County Free Library

San Bernardino, San Bernardino County
  San Bernardino County Free Library, 364 Mt. View Ave.
    M 18; R 17-42; J 43+; B 6, 37, 50, 53, 63, 65-72, 74-75, 78-79, 83-88, 90-109, 113, 115-118, 121+

San Diego, San Diego County
  San Diego County Free Library, 3532 Meade
  San Diego Public Library, Business and Technology Dept., 8th Ave. and E St.
    M 18, 19; RM 6-7, 10-12, 14, 17-21; R 1-42; J 43+; B 1-11, 13-19, 23-24, 27-28, 30-34, 36-38, 41, 45-47, 49-60, 62+
  San Diego State College Library

San Francisco, San Francisco County
  California State Division of Mines, Headquarters Office
    Complete file
  California Academy of Sciences Library, Golden Gate Park
    M 18, R 2-15, 17-42; J 43+; B 1-6, 9-11, 16, 18-19, 23-24, 27, 30, 32, 36-38, 44-46, 50, 57, 63-119, 121-122, 124+
  Mechanics Institute Library, 57 Post St.
    R 1-6, 8, 11-42; J 43+; B 1-7, 9-12, 16, 18-26, 28-31, 36-38, 41-44, 49-76, 78-91, 93-119, 121+
  San Francisco Public Library, Civic Center
    M 18, 19, RM 1-12, 14-21; R 1-2, 4-18, 19a,b,c, 20-42; J 43+; B 1-6, 10-12, 16, 18, 23-24, 27, 30, 32, 36-38, 41, 44, 46, 49-50, 53, 56-57, 60, 63-123, 125-137
  San Francisco State College Library, Buchanan at Waller St.
  U. S. Dept. Agriculture Library, San Francisco Branch, 626 Appraisers Bldg.
    R 16, 39b,c,d, 40-42; J 43+; B 27, 38, 44, 46, 50, 57, 60, 64, 66, 68, 70-72, 74, 76-79, 83, 85+
  University of San Francisco Library, 2130 Fulton St.

San Jose, Santa Clara County
  San Jose Public Library, 110 South Market St.
  San Jose State College Library
    M 18; R 1-12, 29-42; J 43+; B 2-3, 9-12, 16, 18, 21-23, 25-26, 28-30, 32, 36, 38-48, 50-53, 55, 57-65, 68, 70-72, 74, 76-77, 79, 83, 86, 88, 92-94, 96-104, 106+
  Santa Clara County Library, Hall of Justice
    R 26a, 29b, 30a,c, 31-42; J 43+; B 79, 113, 124, 126-127, 131, 135, 137

San Luis Obispo, San Luis Obispo County
  San Luis Obispo Public Library, 690 Monterey St.

San Mateo, San Mateo County
San Mateo Public Library, 129 2nd Ave.

Santa Ana, Orange County
Orange County Free Library, 1104 B West 8th St.
R 11, 20a, 30b, 31d, 32c,d, 33c,d, 34, 35d, 36a, 37b,d, 38-42; J 43+; B 92, 103-105, 111, 113-118, 122-128, 131+
Santa Ana Public Library
R 6, 9, 11-42; J 43+; B 47, 49, 53-55, 64-65, 74, 76-79, 83, 86, 88, 90-95, 98-99, 102-104, 106-110, 112-116, 118, 121, 123-124, 130+

Santa Barbara, Santa Barbara County
Santa Barbara Public Library
M 16, 18, 19; R 2, 6-9, 11-15, 17, 18a,b,c,d,e,f,g,h,i,k,l, 19-21, 22a,b,c, 23, 24c,d, 25-39, 40a,b,d, 41-42; J 43+; B 3-6, 10-11, 19, 30, 44, 46-47, 49-56, 64-65, 67-74, 76-79, 83-84, 86-88, 90-97, 99-119, 121+
Santa Barbara State College Library
M 16, 18; RM 20; R 11, 14, 17, 18g,h,i,j,l, 19b,c,d, 20a,b,d, 21a, 22c, 23a,b,d, 24a,d, 25c, 26a,d, 27b, 28a, 29b, 30b, 31a,c,d, 32-33, 34b,c, 35-38, 39a,b,c, 40-42; J 43+; B 23, 46, 50, 74, 76-77, 79, 83, 86, 88, 90, 98, 99, 101-104, 107, 109-112, 114-119, 121-122, 125-126, 128-132, 135-137
Westmont College Library, 55 La Paz Road
M 18; R 11, 17, 18g,h,i,j,l, 19b,c,d, 20a,b,d, 21a, 22c, 23a,b,d, 24a,d, 25c, 26a,d, 27b,d, 28a, 29b, 30a,b, 31a,b,d, 32-33, 34b,c, 35-42; J 43+; B 50, 76, 79, 98-99, 104, 115, 118, 125, 130-131, 133-137

Santa Clara, Santa Clara County
Santa Clara University, Varsi Library

Santa Cruz, Santa Cruz County
Santa Cruz Public Library, Church St.

Santa Monica, Los Angeles County
Santa Monica Public Library, 503 Santa Monica Blvd.
R 16, 18a,b,c,d,e,g,h,i,k,l, 19, 20a,b,d, 21a,b,d, 22a,c, 23-26, 27a,b,d, 28-29, 30d, 31, 32a,d, 33-34, 35a,b,c, 36a,b,c, 37-42; J 43+; B 19, 23, 37, 63, 70, 72-76, 78-84, 86-88, 90-96, 98-102, 104-115, 117-119, 121-122, 124+

Santa Paula, Ventura County
Dean Hobbs Blanchard Memorial Library
M 18; R 17, 36-42; J 43+; B 67, 69, 72, 74, 78-82, 89, 91, 104, 107-111, 113, 118, 122-125, 130-131, 133+

Santa Rosa, Sonoma County
Santa Rosa Free Public Library
R 14a,c,d,f, 15d, 16, 18h,k, 19b,c, 20b,c,d, 21a,b,d, 22-23, 24a,b, 25, 26c,d, 27, 28c, 29-30, 31b,c,d 32-34, 35d, 37-42; J 43+; B 68, 71, 76, 79, 83, 85-86, 88, 90, 93-94, 96-97, 100-105, 107, 110-114, 116, 121-122, 125-137

Sonora, Tuolumne County
Sonora Public Library, Box 181
Tuolumne County Free Library

South Pasadena, Los Angeles County
South Pasadena Public Library, 1111 El Centro

Stanford, Santa Clara County
Stanford University Libraries, Documents Division
M 16, 18, 19; RM 1-21; R 1-15, 16b, 17-42; J 43+; B 1+

Stockton, San Joaquin County
College of the Pacific Library
Stockton Public Library, Market and Hunter Sts.
M 18; RM 2-5, 10-11, 20-21; R 3-30, 31d, 32-42; J 43+; B 1, 3-14, 16-17, 19, 23, 27, 30-34, 36-38, 46-47, 49, 51-60, 64-65, 68, 70-84, 86-90, 92-94, 96-119, 121-130, 132+

Susanville, Lassen County
Lassen County Free Library, Court House
R 3-8, 16-26, 27d, 28-42; J 43+; B 49, 56, 60, 68, 71-108, 110-114, 116-119, 121-123, 135+

Taft, Kern County
Kern County Free Library, Taft Branch

Vallejo, Solano County
Vallejo Public Library, Box 272
R 10, 33c, 34a, 37d, 38, 39b,d, 40a,b, 41d, 42a,c,d; J 43+; B

Ventura, Ventura County
Ventura County Free Library, Box 771
M 18; RM 7, 11, 14, 18; R 17-18, 19a,b, 20-30, 31a,b,d, 32-35, 36b,c,d, 37b,c,d, 38-39, 40a,b,c, 41-42; J 43+; B 4, 9-10, 12, 21-23, 25-32, 39-44, 47, 50-55, 58-59, 61, 63-65, 68-71, 74, 76-84, 86-119, 121-128, 131+
Ventura Junior College Library
R 21-27, 42; J 43+; B

Visalia, Tulare County
Tulare County Free Library
Visalia Public Library, Locust and Oak.
R 24, 25a,b, 26b,c,d, 27-28, 29a, 30c, 31, 32a,c,d, 33, 34a,c, 35a,c,d, 36-42; J 43+; B 53, 57, 63, 66, 76, 79, 85, 87 91-92, 98-99, 104, 108, 121-126, 128+

Weaverville, Trinity County
Trinity County Free Library
R 29a, 30b, 31b,c, 33b, 35-42; J 43+; B 98, 104, 107, 117-126, 128+

Whittier, Los Angeles County
Whittier Public Library, Greenleaf and Bailey Sts.

Willows, Glenn County
Glenn County Free Library
R 2, 18a,b,c,d, 19a,b,c, 21-22, 23a,b,d, 24b,c,d, 25-26, 27a,c,d, 29, 30b,c, 31a,c,d, 32a,c,d, 33-35, 36a, 37d, 38-41, 42a; J 43+; B 71-72, 75-77, 83, 86-88, 90, 94, 96-97, 100-105, 107-109, 112, 114, 117-119, 123-124, 126-128, 132-133

Woodland, Yolo County
Yolo County Free Library
R 40d, 41, 42b,c,d; J 43+; B 67, 71, 74, 76, 91, 99, 118, 124-125, 128+

Yreka, Siskiyou County
Siskiyou County Free Library

Yuba City, Sutter County
Sutter County Free Library, Mission Hall

States Other Than California

Alabama

Birmingham
Birmingham Public Library
M 19; R 11, 17, 18d,g,h,i,j,k,l, 19, 29b,d, 21-28, 30d, 31b,c,d, 32-42; J 43+; R 9, 23, 50, 74, 76-79, 83, 86, 88, 90-95, 99, 101-103, 105-108, 110-114, 116-119, 121-122, 125+

University
University of Alabama Main Library
M 19; RM 1-12, 15-16, 18-19; R 1-5, 6a, 7-13, 15, 17, 18a,b,d, 19d, 20c, 21d, 22a,c,d, 23c, 25a, 27c, 28b, 31b, 33d, 34-37, 42c,d; J 43+; B 1-49, 51-75, 82-94, 96-97, 100-103, 105, 107, 109, 113, 115-117, 119-121, 124, 131, 135-137

Alaska

College
University of Alaska Library
R 11, 16, 18-19, 20b,c,d, 21d, 22b,d, 23-24, 25a,c,d, 26a,b,d, 27, 28a, 30c, 31c, 34b, 36b,c,d, 37d, 38a,b, 39a,d, 40-41, 42b,c,d; J 43+; B 72, 90, 100, 126-128, 131-133, 137

Colorado

Boulder
University of Colorado Libraries, Documents Division
R 2, 4-13, 35c,d, 36a,c,d, 37d, 38-42; J 43+; B 2, 4, 6, 9-11, 23-24, 27, 30, 32, 35-36, 41, 45-46, 49-50, 53, 56-57, 60, 63-68, 93, 97, 102, 104, 113, 115, 118, 123-125, 127

Denver
Denver Public Library, Science and Engineering Department
R 1-42; J 43+; B 1-7, 9-11, 13-33, 35-40, 42-46, 48-58, 60+

Colorado, Continued

Golden
Colorado School of Mines Library
M 18, 19; RM 3-12, 14-21; R 4, 6-42; J 43; B 1-7, 9-14, 16, 18-19, 21-31, 34, 36-39, 42-46, 50-51, 57-58, 61-71, 73-96, 98-137

Connecticut

Bridgeport
Bridgeport Public Library, 925 Broad St.
R 11-15, 17-25, 37d, 38-39, 40a,b,c, 41-42; J 43+; B 61, 65, 68, 70-71, 74, 83, 86-88, 90, 93-97, 100-101, 113, 125, 135

Hartford
Connecticut Geological and Natural History Survey, State Library

New Haven
Yale University Library, Box 1603a, Yale Sta.
R 1-42; J 43+; B 1-8, 10-14, 16-18, 21-24, 27, 30-32, 36-37, 42-43, 45-60, 63-65, 67, 69+

Florida

Gainesville
University of Florida Library

Illinois

Chicago
Chicago Public Library, Document Division
M 16, 18, 19; R 6-13, 18a,b, 20c,d, 21-29, 30a,c, 31-42; J 43+; B 3, 5-18, 21-24, 27, 30-35, 45-46, 50-55, 57, 76-79, 83-84, 86-105, 107-119, 121-123, 125+
University of Chicago Library
R 1-42; J 43+; B 2-3, 6, 18-19, 23, 32, 36-37, 45-46, 50 63-119, 121+

Evanston
Northwestern University Library, Documents Dept.
M 16, 18, 19; R 2, 7-8, 11-12, 17, 29-42; J 43+; B 23, 27, 49-59, 53, 63, 65, 68-69, 78-79, 87-92, 98, 101-108, 110, 112-113, 115-119, 121+

Indiana

Bloomington
Indiana University, Geology Library
R 6-7, 11, 33-36, 39-42; J 43+; B 1, 9, 50, 76-79, 86, 98-99, 104, 106, 108, 113, 115-117, 121, 123, 131, 135-137

Indianapolis
Indiana State Library, 140 North Seventh Ave.
R 1-42; J 43+; B 2-4, 6, 8-15, 18, 23-24, 50, 63, 68-70, 72, 78-79, 84, 89-91, 97-99, 104, 106-107, 113, 115, 119, 123, 131+

Iowa

Ames
Iowa State College Library
R 9-12, 21-42; J 43+; B 4, 6, 25, 37, 40, 63, 67, 69, 72, 74-86, 88, 100+

Kansas

Lawrence
University of Kansas Library

Kentucky

Lexington
University of Kentucky, Geology Library, 103 Miller Hall
R 2, 4, 6a, 7-17, 18b,c,d,e,f,g,h,i,j,k,l, 19-28, 29b, 30a,b, 31a,b,d, 32-42; J 43+; B 2-6, 9-11, 16, 19, 23-24, 27, 32, 37, 46, 50, 57, 61 63-65, 67-84, 86, 88-96, 98+

Louisiana

Baton Rouge
Louisiana State University, Geology Library
R 6, 9-11, 13, 17, 18c,g,h, 19d, 21d, 25a, 26a,d, 27a,b,d, 28a,c, 29-42; J 43+; B 3, 5, 9-11, 23, 32, 46, 56-57, 63-66, 68-72, 74, 76-79, 83-97, 99-105, 107-108, 110, 112+

Maryland

Baltimore
Enoch Pratt Free Library, Industry and Science Department
Johns Hopkins University, Geology Library

Massachusetts

Boston
Graduate School of Business Administration, Baker Library
J 43+ ; B 68-70, 73-74, 78-86, 88, 90, 92-98, 100-103, 105, 107, 109-112, 114, 116, 118, 125, 130-132, 135
Boston University, College of Liberal Arts Library, 688 Boylston St.
Massachusetts State Library, 341 State House
M 16, 19 ; R 1-17, 18d,e,f,g,h,i,j,k,l, 19-42 ; J 43+ ; B 1-19, 21-25, 50, 73-74, 76-83, 86, 88, 90-95, 98-99, 101-112, 114, 116-119, 121+

Cambridge
Harvard University, Museum of Comparative Zoology Library
Massachusetts Institute of Technology Library, 77 Massachusetts Ave.
M 18 ; RM 7, B 2, 4-14, 16-42 ; J 43+ ; B 1-13, 15-16, 18-19, 21+

Northampton
Smith College Library
J 43+ ; B 77, 86, 90, 102-108, 115, 117-119, 121, 124, 127

Michigan

Ann Arbor
University of Michigan General Library

Detroit
Detroit Public Library, Technology Dept., 3201 Woodward Ave.
R 6-7, 9-13, 18-30, 31a,b,d, 32b,c,d, 33, 34b,c,d, 35-42 ; J 43+ ; B 3, 7-14, 16, 74, 78-79, 84-108, 110, 112-114, 116-119, 121-128, 131, 133+

East Lansing
Michigan State College Library
R 12, 20-42 ; J 43+ ; B 6, 10, 16, 21, 23, 27, 32, 37, 50, 56, 65, 67, 69, 71-72, 74, 76, 78-79, 85, 89-113, 115-119, 121-133, 137+

Houghton
Michigan College of Mining and Technology Library
R 1-13, 18a,d,e,f,g,h,i,j.k.l, 19b,c, 24d, 25-30, 31b,c,d, 32-33, 34c,d, 35a,c,d, 36-42 ; J 43+ ; B 3-4, 9-12, 16, 18, 60, 77, 86, 96-97, 101-103, 105-110, 112-114, 116-119, 121-138+

Minnesota

Minneapolis
Minneapolis Public Library, Technical Dept., Hennikin at 10th
R 8-12, 30-42 ; J 43+ ; B 1-6, 9, 23-24, 27, 30, 32, 36-38, 46, 69, 71, 79, 84, 88, 90-92, 94-95, 97-103, 105, 107-112, 114, 116-119, 122-124, 126, 128+
University of Minnesota Library
University of Minnesota School of Mines Library
RM 10 ; R 3-15, 16b,c, 17-28, 29b, 30-32, 33b,c,d, 34, 35a,b, 36b, 37b,c, 38, 39a,b. 40a,d, 41-42 ; J 43+ ; B 1-6, 9, 11, 16, 18-19, 23-24, 27, 30, 32, 36-38, 46. 50. 63-104, 106-107, 113, 131, 137
University of Minnesota, Geology Library, Pillsbury Hall
M 18 ; R 1-42 ; J 43+ ; B 1-7, 10-11, 16, 18, 23, 27, 30, 32, 37, 46, 40, 63-71. 73-77, 79, 82, 84-108, 111-119, 121+

Saint Paul
James Jerome Hill Reference Library
M 18 ; R 16, 29, 32a,b, 31-42 ; J 43+ ; B 18, 50, 76, 78-79, 95, 99, 104, 107-119. 121+

Missouri

Columbia
University of Missouri, Geology Library, 113 Swallow Hall
R 18a,c,d,e,f,g,h,i,j,k,l, 19a, 20-42 ; J 43+ ; B 5-6, 9, 23, 38, 44, 55, 63, 66, 70. 72, 74, 76, 78-79, 83, 85, 87-105, 107-130, 132-133, 138+

Kansas City
Kansas City Public Library, Document Division
M 16, 19 ; R 18b,c,d,e,f,g,h,i,j,k,l, 19-25, 26a,c,d, 27-42 ; J 43+ ; B 50, 65-66, 70-42, 74-83, 85-90, 93-94, 96-105, 107-119, 121+

Rolla
Missouri School of Mines Library
R 6-14, 17, 18-42 ; J 43+ ; B 2-3, 5-6, 9-10, 15, 23-24, 27, 30-32, 37, 41, 46, 49-50, 57, 60+

Missouri, Continued

St. Louis
St. Louis Public Library, Olive, 13th and 14th Sts.
Washington University, Geology Library
M 18, RM 8, 12, 17, 19-21; R 3, 6-33, 34b,c,d, 35a,b,d, 36-42; J 43+; B 2, 5-6, 8-10, 16, 23, 27-32, 37-38, 42-43, 45-46, 50, 55-57, 61-74, 76-79, 83-113, 115-116, 118, 122+

Montana

Butte
Montana School of Mines Library
M 18, 19; RM 11, 21; R 4, 6-42; J 43+; B 2, 4-6, 9-10, 12, 16-17, 19, 22-44, 46-53, 55-119, 121-135, 138+

Missoula
Montana State University Library
R 29-31, 32b, 33-42; J 43+; B 23-24, 27, 30-32, 36, 38, 45-46, 50-74, 76, 78-105, 112+

New Hampshire

Hanover
Dartmouth College Library
R 1-17, 18f,g,h,i,j,k,l, 19-20, 21b, 22-42; J 43+; B 2, 6, 9-10, 12-18, 21, 23-26, 28-30, 32, 36-37, 39-44, 48, 50-53, 55-56, 58-59, 61, 63-65, 68, 70-72, 74-79, 83, 85-88, 90-96, 98+

New Jersey

New Brunswick
Rutgers State University Library
M 16, 18; RM 12-14, 17, 20-21; R 1-17, 18g,h,i,j,k,l, 19a,b,c, 20a,b,d, 21a,b,c, 22b,c, 23a,b,d, 24, 25b,c,d, 26-27, 28a,c, 29, 30a,b, 22b,c, 23a,b,d, 24, 25b,c,d, 26-27, 28a,c, 29, 30a,b, 31-42; J 43+; B 1, 3, 5-9, 11, 13-14, 16, 18, 27, 50, 53-56, 64-65, 68, 70-71, 74, 76-79, 83, 86, 88, 90, 92-95, 98-100, 102-104, 106-109, 113-114, 118-125, 127-137

Princeton
Princeton University Library
R 29-42; J 43+; B 2, 4-6, 9-10, 23-24, 27, 31-32, 37, 46, 50, 56-57, 61-119, 121-126, 131, 135+

New Mexico

Albuquerque
University of New Mexico Library
R 6-7, 10-11, 17, 29b, 30, 31a,b,d, 32-33, 34b,c,d, 35-42; J 43+; B 23, 32, 46, 60, 74, 77, 79, 83, 86, 88, 90, 98-99, 101-104, 107, 109-112, 114-119, 121+

Socorro
New Mexico School of Mines Library

New York

Albany
New York State Library

Hamilton
Colgate University Library
R 18e,f,g,h,i,j,k,l, 19-20, 21a,b, 22c, 23a,b,d, 24a,b,d, 25c,d, 26a,d, 27a,b,d, 28a, 29-37, 38a,c, 39-40, 41c,d, 42a,b,c; J 43+; B 76, 78-79, 99, 104, 118-119, 121-123, 125-131, 133+

Ithaca
Cornell University Library
M 16; RM 6, 8-9; R 1-14, 17-21, 22b,c,d, 23-42; J 43+; B 1-10, 15-16, 18, 23, 27, 31-32, 36-38, 45-46, 50, 56-57, 63, 65-67, 71+

New York City
Columbia University, Butler Library, Acquisition Dept., South Hall
Columbia University, Engineering Library
Engineering Societies Library, 29 West 39th St.
M 16, 18, 19; RM 6-12, 14-15, 17-20; R 1-42; J 43+; B 1-19, 22-32, 34-39, 41+
Marvyn Scudder Financial Library, South Hall, Columbia University
New York Public Library, 5th Avenue at 42nd Street

Syracuse
Syracuse University Library

North Carolina

Chapel Hill
University of North Carolina Library
M 18; RM 6-12, 14-19; R 2, 4, 6-7, 9-15, 17, 29-30, 31a,b,d, 32, 33a,b,c, 34d, 35d, 36a,c,d, 37c,d, 38, 39b,c,d, 40-41, 42b,c,d; J 43+; B 2, 4, 6, 9-10, 16, 18, 21, 23-25, 27-30, 32-34, 36-38, 41, 44, 46, 49, 53, 56-57, 60, 63-69, 71, 73-74, 76-79, 83-108, 110-111, 113-115, 117, 127, 131, 133+

Raleigh
North Carolina State College D. H. Hill Library
R 29-33, 34b,c,d, 35-42; J 43+

Ohio

Cincinnati
Cincinnati Public Library, 629 Vine St.
R 40-42; J 43+; B 17, 30-31, 37-39, 50, 57, 63, 65, 67, 69, 72-83, 85-95, 97-99, 101-102, 104, 108, 113, 115, 118, 123-125, 127+
University of Cincinnati General Library
RM 2, 16, 18, 21; R 1-4, 7-14, 25-42; J 43+; B 1, 3-11, 15, 23-24, 27, 31-32, 36-38, 42-43, 46, 49-50, 56-57, 61, 63-65, 67-70, 72-75, 77, 84, 86-87, 90-91, 94-95, 98-99, 101-109, 111-112, 114-115, 117-119, 121+

Cleveland
Cleveland Museum of Natural History, Reference Library, 2717 Euclid Ave.
R 30a,b, 31-42; J 43+; B 101-107, 115, 118, 125, 131, 133-137
Cleveland Public Library, 325 Superior Ave.

Oberlin
Oberlin College Library

Toledo
Toledo Public Library, Technology Dept.
R 20a,b,d, 21a,b,c, 22-24, 25c,d, 26-27, 28c, 29-30, 31b,c,d, 32-42; J 43+; B 23, 50, 53, 64-66, 73-74, 76-79, 83, 86-88, 90-96, 98-104, 111, 131, 135-137

Oklahoma

Norman
University of Oklahoma Geological Library

Stillwater
Oklahoma A. & M. College Library

Tulsa
University of Tulsa Library, 7th and College
R 2, 5-26, 27a,b,d, 28a,c, 29-41, 42a,c,d; J 43+; B 3-11, 16, 21, 23-24, 27, 32, 36-37, 46, 50, 57, 63-111, 113, 115-118, 120-121, 125, 131, 135-137

Oregon

Corvallis
Oregon State College Library, Serials Division

Eugene
University of Oregon Library
M 18, 19; R 4-5, 8-9, 11-13, 16-42; J 43+; B 4-6, 9, 23, 27, 31-32, 46, 50, 57, 61-108, 110+

Portland
Library Association of Portland, 801 S. W. 10th Ave.
M 18, 19; RM 1-11, 14, 20-21; R 6-7, 9, 11-42; J 43+; B 2-6, 9-12, 14-16, 18-19, 23-27, 32, 36-37, 45-46, 50, 53-68, 70-72, 74-96, 98-99, 101-119, 121+

Salem
Oregon State Library, State Library Bldg.
M 19; R 2, 6-13, 16-42; J 43+; B 3-4, 6-14, 16, 23, 27, 37, 50, 57, 62, 64-67, 69-70, 82-91, 93-119, 121+

Pennsylvania

Bethlehem
Lehigh University Library
RM 4, 8, 10, 12, 19-21; R 6-8, 11-15, 18-42; J 43+; B 2-7, 9, 11-16, 23, 27-29, 31-35, 37-38, 46-48, 50, 57, 60, 63-65, 67-72, 74-88, 90-92, 94-105, 107-133, 138+

Pennsylvania, Continued

Philadelphia
  Franklin Institute Library
    R 2-13, 16-17, 18c,d,g,h,i,j,l, 19, 20a,b,d, 21a,b,c, 22-23, 24a,b,c, 25b,c,d, 26a,b,c, 27, 28a,c, 29-42; J 43+; B 1-6, 8-14, 16-24, 32, 36-38, 44-45, 50, 53-60, 63-78, 82-91, 93, 95, 97-98, 102-104, 106-113, 115-119, 121-123, 125+
  Philadelphia Academy of Natural Sciences, 19th and The Parkway
    M 16, 18; RM 7; R 3-14, 16-42; J 43+; B 1-4, 6, 9-11, 16, 19, 23, 37-38, 46, 50, 63, 65, 67-69, 72, 74-133, 137+
  Philadelphia Free Library, Public Documents Dept., Logan Square
    RM 3-8, 10-21; R 11, 17-25, 26a,b,c, 27-42; J 43+; B 1-7, 9-11, 23-25, 27, 30-32, 36-41, 45-48, 50-53, 56-65, 67, 70-88, 90+
  University of Pennsylvania Library, 34th St. at Woodland Ave.

Pittsburgh
  Carnegie Library of Pittsburgh, 4400 Forbes St.
    M 16, 18, 19; RM 21; R 4, 6, 8-11, 17-42; J 43+; B 1-6, 8-12, 15-46, 50-119, 121-123, 125+

State College
  Pennsylvania State College Mineral Industry Library

Rhode Island

Providence
  Brown University Library
    J 43+; B 6, 9, 23, 27, 32, 37, 46, 50, 57, 64-79, 83, 85-88, 93-123, 125

South Dakota

Rapid City
  South Dakota School of Mines and Technology Library
    M 16; R 16-42; J 43+; B 27, 50, 57, 63-65, 68, 71-74, 76-79, 83-118, 121+

Tennessee

Nashville
  Joint University Geology Departmental Library
    R 2-17, 18c,d,f,g,h,i,j,l, 19-42; J 43+; B 1-6, 9-12, 16, 18-19, 23-24, 30, 32, 36-39, 44, 46-48, 53, 56-57, 70, 63+

Texas

Austin
  University of Texas Bureau of Economic Geology

College Station
  Texas A. & M. College, Geology Dept. Library

Dallas
  Southern Methodist University

El Paso
  El Paso Public Library, Carnegie Square

Fort Worth
  Texas Christian University, Mary Couts Burnett Library
    R 39c,d, 40b,c,d, 41-42; J 43+

Houston
  Houston Public Library

Utah

Logan
  Utah State Agricultural College Library
    R 32d, 33, 34a,b,c, 35-36, 37a,c, 38c, 39a,b, 40-42; J 43+; B 3, 6, 9, 65, 68, 70-71, 74, 76, 86, 90, 93-94, 103, 106-107, 116-117, 131, 135-137

Washington, D. C.

U. S. Government
  Department of Commerce Library, Commerce Bldg.
  Library of Congress
  Bureau of Mines Library
    M 16, 18; RM 308, 10-21; R 1-11, 13-17, 20-42; J 43+; B 3, 5-6, 9, 18-19, 24, 30, 32, 36, 38-47, 50-53, 56-57, 60-79, 83-119, 121-122, 124-127, 130+
  Smithsonian Institution Library

Washington

Pullman
State College of Washington Library, Serials Section
RM 12; R 1-2, 6-14, 16-18, 29-42; J 43+; B 1-6, 9-11, 15-16, 18-19, 23-24, 32, 37-38, 41, 44-46, 50-51, 53, 56, 60, 63-74, 76-79, 83-112, 114, 116-119, 121-133, 137-138+

Seattle
Seattle Public Library, 4th and Madison
M 18; RM 12-13; R 1-14, 15-42; J 43+; B 2-6, 9-11, 15-16, 18, 23, 27, 30, 32, 36-38, 45-46, 49-50, 53-59, 61-131, 133+
University of Washington Library
RM 1-10, 12-21; R 1-13, 16-17, 31b,c, 32a, 33b,c,d, 34-37, 38a,b, 39c,d, 40-42; J 43+; B 2, 5-6, 9, 15, 18, 23, 27, 31-32, 36-41, 44-46, 49-50, 53, 56-61, 63-74, 76-79, 83-91, 95, 98-99, 102, 104, 106, 108-118, 123+
University of Washington, Gifts and Exchanges

Spokane
Spokane Public Library, Reference Dept., S 18 Cedar St.
M 16, 19; R 2, 5-11, 13-14, 16, 18-20, 21b,c,d, 22a,b,c, 23a,b,d, 24-28, 31-42; J 43+; B 2, 5-6, 9-10, 19, 23-26, 36-38, 44, 46, 57, 60, 63-114, 116-119, 121+

Tacoma
College of Puget Sound Library
J 43+ ; B 3, 92, 94, 96, 98, 101-102, 108, 111, 117
Tacoma Public Library

Wisconsin

Madison
University of Wisconsin Library, Department of Geology
M 16; RM 12, 17, 19-20; R 3-17, 18c,d,e,f,g,h,i,j,k,l, 19-42; J 43+; B 1-14, 16-19, 21-23, 28, 30-32, 34-44, 46-48, 50, 53-56, 63-119, 121+

Milwaukee
Milwaukee Public Library, 8th and Wisconsin

Wyoming

Laramie
Wyoming State Geological Survey Library, University of Wyoming
R 11, 28b, 31a, 32, 34b,c,d, 35a, 36-39, 40a,d, 41-42; J 43+; B 4, 25, 85, 91-92, 95, 99-100, 102-106, 108-109, 113, 115-117, 119, 121-122, 126, 128-137

Foreign

Australia

Adelaide

Public Library, Museum and Art Gallery

University of Adelaide, Barr Smith Library

Sydney

Public Library of New South Wales

R 17, 29-42; J 43+; B 76-94, 96-99, 101-102, 107-112, 114, 116, 118-119, 121, 126, 128-131, 133-138+

Canada

Ottawa

Bureau of Geology and Topography Library

Dept. of Mines and Resources, Bureau of Mines Library, Lydia St.

Geological Survey of Canada Library, Victoria Memorial Museum Bldg.

Vancouver

University of British Columbia Library

R 8-9, 11-12, 16-22, 23b,c,d, 24c, 37a,b,c, 38-42; J 43+; B 5, 9, 56-57, 63-65, 67-74, 76-77, 79, 83-88, 90-91, 93-97, 100-104, 106+

England

London

Geological Society Library, Burlington House, Piccadilly, W. 1

R 1-4, 6-8, 10-13, 27-42; J 43+; B 1-5, 11, 16, 50, 77-79, 95, 98-99, 121, 131, 135-137

Patent Office Library, 25 Southampton Bldgs., Chancey Lane, W. C. 2

R 3-15, 17-42; J 43+; B 1-24, 27, 30-41, 45, 48-54, 56-66, 72, 74, 76, 78-79, 83, 85-86, 88-91, 93-105, 107-123, 125+

Science Museum Library, South Kensington, S. W. 7

M 16; R 14-15, 18-32, 33a,b,c, 34-42; J 43+; B 23, 37, 46, 50, 69, 72-73, 75-86, 91+

Russia

Moscow

The Lenin State Library

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